SOIL AND SITE VARIABILITY IN THE NORTHEAST WENATCHEE MOUNTAINS, WASHINGTON

by

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This is to certify that I have examined this copy of a master's thesis by

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and have found that it is complete and satisfactory in all respects,
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DEDICATION

I dedicate this thesis to Steve Dolan, who has supported me finically and emotionally over the last two years; and always encouraged me, whether I wanted encouragement or not. Steve, without you this would not have been possible.

CHAPTER 1: INTRODUTION

One of the key concepts that decades of research in soil science has conceived is the five major soil-forming factors; climate, organisms, parent material, topography, and time (Brady 1990). When soils differ spatially across a landscape these are the factors, and reasonably so, that explain soil variability. For example, vegetation can affect the soil by stabilizing slopes through root structure, increase organic matter through root turnover, and leaching soil with acids released in the decomposition of leaf matter.

The Wenatchee Mountains, part of the east slopes of the central Washington Cascade Range, exhibit highly variable topography. Ponderosa pine (*Pinus ponderosa* Dougl. ex Loud.)/Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests on steep slopes are characteristic of the area. Soil spatial patterns can be difficult to determine on landscapes with high variability. However, the climate, parent material, age, and even forest species are relatively constant over much of this area. Therefore, topography and vegetative cover could be expected to explain most soil variability.

In the Wenatchee Mountains twelve plots were established for the national Fire and Fire Surrogate (FFS) study. The FFS research project is studying applications of various thinning, burning and/or fuel reduction techniques for use in forests that have high fuel loading due to fire suppression (USDI, USDA Joint Fire Science Program 2000). The treatment applications will be evaluated for ecosystem restoration effectiveness. Prior to treatment application, it is necessary to determine soil types within the research area and how the soils vary within and among the twelve research plots.

Ideally, this information could be extrapolated to the entire region of the Cascade Mountain east slopes.

The objectives of this research were to report the soil spatial variability of the area and determine if predictable soil patterns or models can be derived. To meet these goals, field data on the soil, vegetation, and topography were collected on two scales. A large-scale sampling method (i.e., blocked by topographic position) (soil profile data) was used to describe the site conditions and derive regression models on soil horizon thicknesses. Due to the extreme topography of the region, topography is expected to be more significant or explain a greater amount of the variability in the soil horizon thicknesses than vegetation. A small-scale data collection method (grid point data) was used to describe the area in more detail and apply the models calculated from the soil profile data. This was to determine the accuracy of the models and the predictability of the soil horizons.

CHAPTER 2: SPATIAL VARIABILITY

Determining the causes of spatial variability within soils can be a daunting and sometimes nearly impossible task. Phillips et al., (1996) discusses three views of soil spatial variability. First, soil spatial patterns are associated with spatial heterogeneity of environmental factors and their interactions, which lead to micro-scale variation (Burrough 1983 as discussed by Phillips et al. 1996). This idea, initiating from the beginnings of soil science, suggests that environmental properties and processes interact to create an existing landscape or soil. As one or more of these properties or processes change across the landscape, the resulting soil will be altered to reflect the change.

Second, soil scientists are limited by knowledge and data, but through increased accuracy and amount of knowledge and data, soil variability can be determined (Phillips et al. 1996). This theory states that all the information necessary to understand soil spatial variability is present in the landscape. However, the ability to collect the appropriate information accurately limits the explanations soil science can provide. If a factor influential in soil formation is unmeasured or inaccurately measured, the cause(s) of soil variability may not be revealed. However, by gaining more knowledge about the processes and factors influencing soil formation, increased and more accurate data can be collected, thus increasing the potential to understand soil variability.

Third, highly variable soils can display "deterministic uncertainty," in that soil variability can exhibit intricate, unpredictable and random patterns (Phillips et al. 1996). This idea opposes the first theory presented above in that soil variability may occur without change in the environmental factors (Culling 1988, Arlinghaus et al. 1992, McBratney 1992, and Phillips 1993a,b as discussed by Phillips et al. 1996). Deterministic uncertainty was used to describe why a site on the North Carolina Costal Plain where parent material, age, climate, and vegetation were constant; however, only 20% of the variability could be explained using topographic and drainage data (Phillips et al. 1996). Although, as stated above, because of pedologists' limited knowledge and data, it is possible that factors not usually considered dominant in soil formation could account for the variability and were unmeasured or inaccurately observed in this case (Phillips et al. 1996), such as past land use or disturbance.

SOIL VARIABILITY AND TIME

Deterministic uncertainty leads to the idea that soil variability increases over time unrelated to the current soil forming factors (Phillips et al. 1996). For example, a small disturbance or variation in the environment can cause inconsistencies in the soil that initially may be imperceptible, but over time, increase (Phillips et al. 1996). By this theory, young soils, although more homogeneous than older soils, would be extremely influential in the spatial variation that would occur at a site over time. Soils that experience many perturbations or minor differences in environmental factors will form highly variable soils. Also, well-developed and relatively stable soils can experience "regressive pedogenesis" from microsite disturbances (Barrett 2001). Erosion and deposition can cause a Mollisol to be altered into an Inceptisol, for instance. As the soil age increases, the likelihood that disturbances will occur at a site should increase (Barrett

2001). An example of this idea is presented in a visual examination of data collected on a chronosequence in northern Michigan. The variability appears to increase in soils greater than 3000 years old (Barrett 2001). These ideas may be important for the Washington FFS sites when considering the old age of the landscape due to lack of glaciation and the potential for disturbance from steep slopes.

SOIL VARABILITY, TOPOGRAPHY, AND LANDFORM

Backslopes, small hummocks, shoulders, and steep convex slopes strongly influence the soil in that thinner soil or A horizon depths are present in these areas (Marron and Popenoe 1986; Miller et al. 1988; Moore et al. 1993; Stolt et al. 1993). Toe- and footslopes have deeper and less developed soils than on the landscape above (Miller et al. 1988; Stolt et al. 1993; Webb and Burgham 1997). Erosion and sedimentation processes are responsible for these patterns. Gessler et al. (2000) discussed topographic influences on the soil in three areas, as: 1) zones of accumulation of particles and water in convergent or concave curvatures, 2) zones of depletion of sediment and water in divergent or convex slope curvatures, and 3) reasonably stable, un-eroded summits (Moore et al. 1993; Stolt et al. 1993; Chen et al 1999), where in situ development can occur (Gessler et al. 2000).

The effect landform has on soil can be extensive. For landscapes with slopes of approximately 50%, average annual soil loss is between 43 and 141 Mg/ha depending on soil texture (Liu et al. 1994). Landform and topographic processes can result in alterations of eluvial and illuvial patterns (Chen et al. 1999), reduced crop yields in areas of erosion and deposition (Miller et al. 1988), and reduced pedogenic development due to moisture differentiations and stability limitations (Ellis et al. 1994).

However, some literature contradicts these generalities. A study in Colorado and Kansas discovered an increase in Bt horizon thickness from summit to shoulder to backslope to footslope, suggesting more soil development downslope (Honeycutt et al. 1990). Swanson (1985) found the least soil development on the shoulders and the most development on the concave valleys in the landscape. Donald et al. (1993) had similar findings, reporting thicker Bt horizons on concave slope positions than convex. The same study concluded that A horizon thickness was greatest on the backslopes independent of the slope curvature (concave or convex) (Donald et al. 1993). The literature suggests, the processes to explain these results begin with erosion causing poorly developed soils on convex shoulder slopes, similar to the findings by Marron and Popenoe (1986), Miller et al. (1988), Moore et al. (1993) and Stolt et al. (1993). However, the weakly developed zones of deposition, from the examples above, are not apparent on these landscapes. Instead, the non-curving or flat backslopes can act as zones of transportation for clay and dissolved material in the sub-surface flow zone. This causes more moisture to accumulate downslope, causing a greater degree of development (Swanson 1985; Honeycutt et al. 1990; Donald et al. 1993). The thick A horizons on backslopes are explained by a deeper water table, allowing vertical movement of material and moisture, resulting in increased development (Donald et al. 1993).

One reason for these inconsistencies is that slope percent and the depth to the water table, or available water, complicates topographic and landform influence on the soil (Archer and Cutler 1983; Marron and Popenoe 1986; Donald et al. 1993; Moore et al. 1993). For example, Marron and Popenoe (1986) found more developed soil on slopes with north-facing aspects compared to south-facing aspects. This was attributed to the role of soil moisture on erosion. The soils on north-facing slopes were found to have more moisture, due to the angle of the sun in the northern hemisphere and fewer rock fragments. This could cause soils on north aspects to be slightly more stable, experiencing slower rates of erosion as soil creep. The dry, south-facing slopes that have shallower soils could be less stable and experience increased rates and speed of erosion such as landslides (Marron and Popenoe 1986).

SOIL VARIABILITY AND VEGETATION

Vegetation and soil properties can have a marked effect on each other. In a study by Amiotti et al. (2000) soils were examined to determine the effect of nearly a century old planting of Monterey pine (*Pinus radiata* D. Don) in native grassland. Despite the regular forest structure, the soils displayed variation related to individual trees. Near the bole of the tree, where the greatest alterations occurred, percent base saturation declined to below 50% in the A horizons, causing the classification to change from Mollisol. Percent calcium and magnesium and pH also decreased near the trunk and percent aluminum increased. These effects declined with distance from the tree until the impacts of the tree were not detectable outside the area of the canopy (Amiotti et al. 2000). Research by Ryan and McGarity (1983) agrees, showing increased soil weathering near the bole of trees caused by the distribution of gross precipitation and throughfall, litterfall, roots, and soil organisms.

Roché and Busacca (1987) examined a sub-alpine site and found that soil can influence vegetation as well. Soils with high stone content were vegetated with grasslands. In slight depressions, the soils were less stony to a depth of approximately 20 cm, with trees present. On mounds, where the reduced stone soil was the deepest, mountain big sagebrush (*Artemisia tridentata* Nutt.) and bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. & Smith) dominated. The differences in vegetation are due to the inherent properties of the soil and the landscape. The flat grasslands receive less moisture from snow, due to wind redistribution, and have a reduced moisture capacity because of the coarse texture. Therefore the droughty nature of these soils leads to grassland vegetation. The sagebrush/wheatgrass mounds and tree depressions are similar in that these soils have greater moisture capacity. However, the depressions may receive more moisture from runoff (Roché and Busacca 1987). In this study the soil properties and the landscape effects determine the potential vegetation.

However, another study suggests the relationships between vegetation and soil may not always be evident. Brosofske et al. (2001) found differences in A horizon properties with different forest type, but no differences in the E and B horizons. This inconsistency was attributed to management techniques that have differentially disturbed the soil surface while having little impact on the lower horizons (Brosofske et al. 2001). Therefore, no significant effects were determined between different forest types and the soil.

OTHER FACTORS AND INTERACTIONS INFLUENCING SOIL

One problem in determining the cause(s) of soil spatial variability lies with separating the interactions of different factors. Lev and King (1999) determined that topography was highly significant in soil development on a lowland under constant permafrost, even though the gradual slope measured only 2.4°. Also, the three soil areas examined demonstrated different soil environments related to drainage, slope position, vegetation, geomorphology, and parent material (Lev and King 1999). All of these factors interact to create the existing soil, however, it is difficult to determine the significance of each factor because of the complexity of these interactions.

King et al. (1999) discuss complex interactions of climate, parent material, and topography relating to the development of a non-calcareous clay loam horizon (horizon type not given) on a limestone plateau in France. The occurrence of this horizon, originating from loess deposits, relates greatly to aspect and slope percent. The aspect that shows the greatest presence of this horizon corresponds with the average angle of the prevailing wind, suggesting wind direction as a factor in the development of the non-calcareous clay loam horizon (King et al. 1999). This demonstrates three soil forming factors interacting to influence soil morphology.

Some interactions are only loosely linked to the five main soil-forming factors, or exhibit interactions so complex quantification of individual effects becomes difficult. Amiotti et al. (2001) investigated a seemingly random pattern of three soil types on a flat landscape with homogeneous vegetation in Argentina. The various development stages suggested time and parent material as the primary causes for the development of different soil, being that topography and vegetation were constant. It was determined that the most developed soil became differentially eroded in the valleys due to flash floods during the middle to late Holocene. Eolian sediments were deposited and filled in the eroded valleys where two different soils developed (Amiotti et al. 2001). This is an example where climate, topography, parent material and time all interact to contribute to the existing soil variability.

This literature demonstrates the complexities of soil development and soil spatial heterogeneity. The most common and often studied factors affecting soil development are climate, vegetation, relief, parent material, and time. In some cases these factors can explain nearly all soil formation and spatial variability patterns (Marron and Popenoe 1986; Miller et al. 1988; Moore et al. 1993; Stolt et al. 1993; Ellis et al 1994; Webb and Burgham 1997; Amiotti et al. 2000; Gessler et al. 2000; Amiotti et al. 2001). However, in other studies, it can be difficult to determine influential factors of soil morphology and variability (King et al. 1999; Phillips 1996; Lev and King 1999; Brosofske et al. 2001). This may be due to incomplete knowledge or data, deterministic uncertainty, or that data were not collected accurately enough to find patterns. It is also possible that knowledge is still missing to fully unravel soil morphology and explain variability. Nevertheless, a certain amount of randomness in soil development may always be present and obscure soil spatial patterns.

CHAPTER 3: METHODS

SITE DESCRIPTION

The study site, one of the national Fire and Fire Surrogate (FFS) sites, is located within the northeastern area of the Wenatchee Mountains, of the eastern Cascade Mountains in central Washington state, USA (47°25'N, 120°50'W) (Figure 3.1). The dry forest of the area consists of Ponderosa pine and Douglas-fir on a steep mountainous to foothill landscape. Elevation ranges from 640-1219 m. Short dry summers are characteristic for the eastern Cascades. Blewett Pass (elevation 1301 m), located approximately 5.5 km west of the study site, has an average annual precipitation of 88 cm, of which 75 cm falls between October and April, mostly as snow, and an average annual temperature of 5° C (NRCS, USDA 2001). Leavenworth, WA (elevation 344 m), ~ 22.5 km north northwest of the site, has an average annual precipitation of 59 cm, of which only 4.4 cm fall between June and August. Average annual snowfall at Leavenworth totals 252 cm (Franklin and Dyrness 1988).

The forest type consists of a Ponderosa pine/Douglas-fir canopy with various shrub and herbaceous species, mixed with pinegrass (*Calamagrostis rubescens* Buckl.). The shrub species are dominated by bitterbrush (*Purshia tridentata* (Pursh) DC.), spirea (*Spirea* sp.), rose (*Rosa* sp.), huckleberry (*Vaccinium* sp.), snowberry (*Symphoricarpos* sp.), and creambush oceanspray (*Holodiscus discolor* (Pursh) Maxim.). Some of the herbaceous species present are arrowleaf balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.), lupine (*Lupinus* sp.), western yarrow (*Achillea millefolium* L.), and Oregon grape

(*Berberis* sp.). Ponderosa pine/bitterbrush associations are found on the drier south slopes with an increase in Douglas-fir canopy on northern aspects. Because of past disturbance and aspect differences on the site, tree ages and densities vary from old growth (~ 350 years old) pine stands to <10-year-old regenerating Douglas-fir.

The site has an extensive history of natural and anthropogenic disturbance. Prior to 1900 the forests in this region are thought to have experienced frequent low intensity fires. As Europeans began to settle in the area, the land was utilized for logging and grazing. In the eastern portion of the study site, terraces were artificially created and non-native species were planted to control increased rates of erosion as well as natural erosion from steep slopes. Fire suppression became a common practice and as a result the site displays patches of very dense "dog-hair" forest. This forest structure has contributed to recent high severity wildfires in surrounding areas. All twelve of the study plots have experienced various amounts of disturbance from fire, logging (in the 1930's and 1970's mostly), terracing, grazing, erosion, insects (e.g., bark beetles) and disease (e.g., dwarf mistletoe).

The bedrock of this area dates back to the Eocene and Oligocene periods (57 – 24 m.y.b.p.) and consists of non-glaciated sandstone with limited amounts shale and conglomerate, all from the Swauk and Chumstick formations (Tabor et al. 1982). Various amounts of other parent materials may also be present; ash deposits from volcanic eruptions and fire, colluvium due to erosion and deposition on steep slopes, and loess. The areas of deposition for these sediments are variable, not well documented, and difficult to trace. The dissected landscape has slopes that can be as great as 90%, but average 45%. Many convergent and divergent areas exist throughout the landscape as ridges and valleys collide, giving the land a folded appearance. Typical soil types found on the site include Haploxerepts, primarily found on the southeast plots, Haploxerolls, Argixerolls and Haploxeralfs found throughout the remaining plots (NRCS Soil Survey Staff 1995).

The characteristics described above vary slightly among twelve study plots (Figure 3.1). The four southeastern plots (Crow 6, Crow 3, Crow 1, and Pendleton) generally have southern aspects and more gentle slopes than the other plots (average 32 %). The three western plots (Ruby, Camas, and Spromberg) are found on the Swauk geologic formation; all the other plots are on the Chumstick formation. Aspects for the western plots are generally southwest for Ruby and Spromberg and southeast to east on Camas. The northernmost plot, Tripp is the steepest of all twelve plots, averaging 64% slope with a north aspect. The remaining plots do not differ much except in aspect, with Slawson and Poison westerly, Sand 19 southwest and Sand 2 bowl-shaped to the north.

FIELD METHODS

Each of the twelve plots within the study site (see Figure 3.1) is at least 9.5 ha. A grid was established within each plot with points every 80m. Each plot contained 15-24 grid points depending on plot size. At every grid point, slope percent, aspect (northerly, southerly, east or west), and slope position (ridge, shoulder, backslope, toeslope, or valley) were recorded. Two by two meter subplots, located at each point, were used to measure erosion, vegetation type (shrub, herbaceous, and grass) and percent cover.

Vegetation variables were measured on a scale of 1-5 where 1=<15%, 2=16-35%, 3=36-60%, 4=61-85%, 5=86-100% and T(trace)=<1%. Canopy cover was also recorded by ocular measure of a 16-meter diameter area at the grid points, using the 1-5 scale. At each grid point soil was dug to a minimum depth of 25 cm; horizon type and thickness were recorded and bulk density cores were collected for analysis.

Three soil characterization pits were also dug on each plot in different topographic positions (ridge, backslope and valley). A fourth pit was dug on an area with little vegetation to insure the full range of vegetation was recorded. The pits were dug to > 1 m or until the rock layer was reached and soil profile descriptions were completed. Bulk density cores were taken from each horizon and bulk density was calculated from oven-dried cores. The top mineral horizons (A, A2 AB, BA, and Bw) were ranked for amount of ash (0 = no ash, 1 = trace, 2 = minor, 3 = major) using a field texturing estimate.

STATISTICAL ANALYSIS

Pit data were used to analyze topographic (percent slope, aspect and slope position) and vegetation (type and percent cover) variables with soil (O, A, Bw, Bt horizon thickness and depth to the C horizon). Also erosion and amount of ash were included in the statistical analysis. Simple linear regressions were conducted with every variable using SPSS© (Version 10.1 for Windows) (SPSS 2000) to determine which variables were significant. Then multiple regressions were conducted using the significant variables to produce models for each horizon thickness. Normality and multicollinearity were tested using residual plots and the variance of inflation factor, respectively. The models created for O and A horizon thickness were applied to the grid point data and mapped in ArcView© (Version 3.2) (ESRI 1996) to determine reliability.

GEOGRAPHICAL INFORMATION SYSTEMS (GIS) ANALYSIS

Using ArcView© (Version 3.2) (ESRI 1996), plot surfaces were created with the Universal Transverse Mercator (UTM) zone 10 and projected in North American Datum 1927 (NAD 27). Plot outlines were taken from a USDA forestry science lab CD-ROM (Salter and Hessburg 2000, unpublished) and grid points were placed using Geographical Positioning System (GPS) points (Garmin 12 GPS, Garmin International Inc., Olathe, KS). At least three GPS points were collected from each plot; the remaining grid points were placed manually. Digital elevation models (DEMs) were used to create 3-dimentional images of the plots at a 10 m resolution. Surfaces were interpolated from the grid points of each plot using a regularized spline method with 0.1 weight and the number of points = 12. O and A horizon thicknesses, measured and predicted, surface erosion, and percent vegetation cover (grass, trees and herbaceous) surfaces were created for each plot. DEM data were to apply to the maps for elevation lines. This included topography on the surfaces; therefore maps of the topographic variables were not necessary. Maps were displayed using ArcGIS© ArcMap (ESRI 1999).

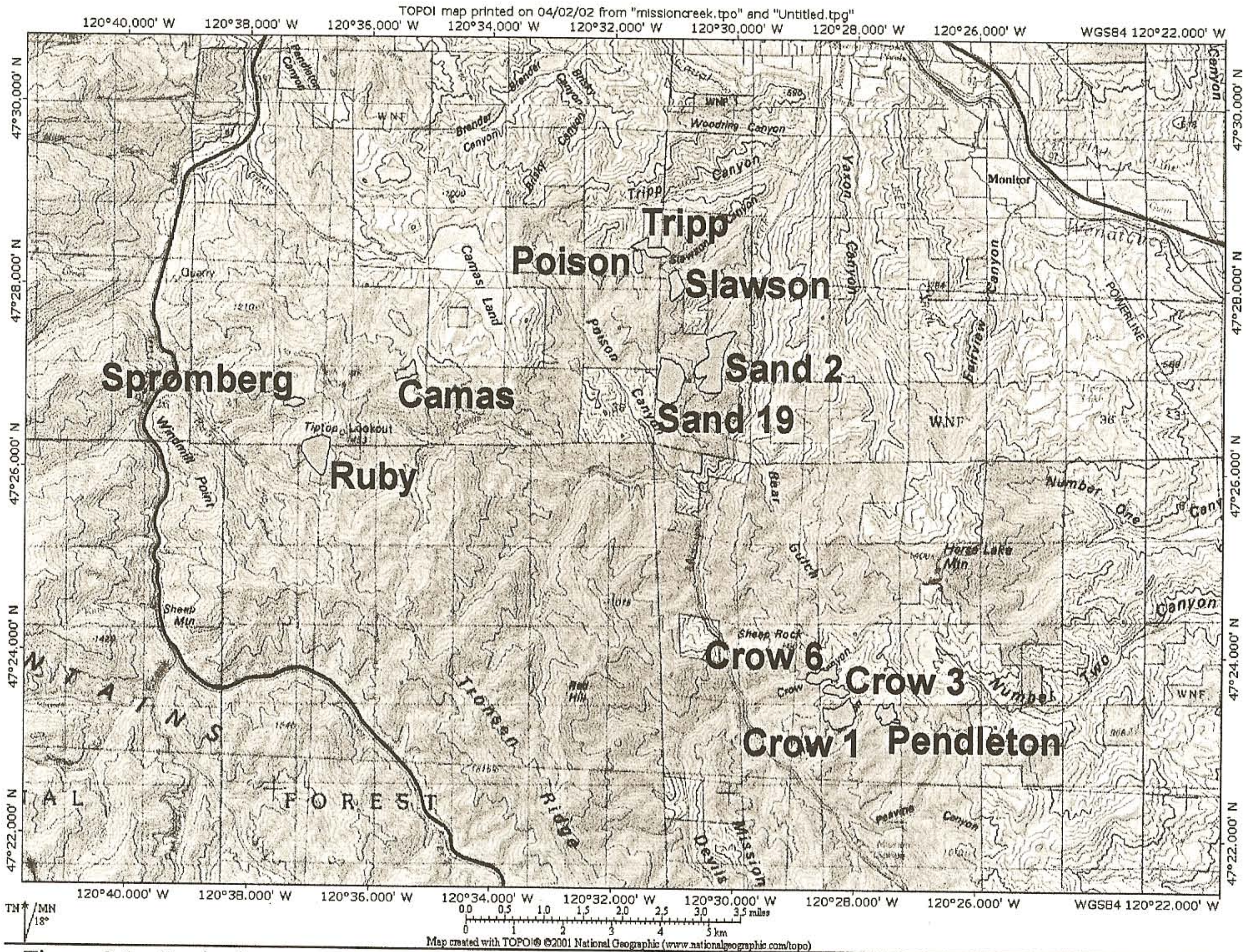


Figure 3.1. Study site map. Plot areas are colored in blue with the plot name identifying the appropriate plot.

CHAPTER 4: SOIL CHARACTERIZATION AND ANALYSIS OF THE SOIL PROFILE DATA

SITE OVERVIEW

The study site consists of sizable plots ranging from 9.5 to 36.2 ha, spread over a wide area to represent a large portion of land with wide ranging variability. This variability is evident in the vegetation cover data. At the locations where soil pits were dug, canopy cover ranged from 0 to 100 %, as did grass cover, and shrub cover was 1-100 %, all with means near 35 %. Exact means could not be calculated due to the categorical system used to measure these variables. Forbs ranged from 0-85 % cover with a mean of ~ 10 %. Even observed erosion had high variability, ranging from 0-100 % with an average of ~ 10 %.

SOIL SURVEY RESULTS

A preliminary soil survey has mapped the following soils on the study site: Blag (Haploxerept), Blewett (Haploxeroll), Borland (Argixeroll), Brisky (Haploxeroll), Cle Elum (Haploxeralf), Dinkelman (Haploxeroll), Nard (Haploxeralf), Shaser (Vitrixerand), Varelum (Haploxeralf), and Yaxing (Argixeroll) (NRCS Soil Survey Staff 1995). While some soil profiles match the mapped series, other soils on the site do not correspond with NRCS soil survey results.

The Nard, Shaser, and sometimes Cle Elum taxonomic descriptions contain E horizons (NRCS 2002), which were not found on any of the soils in this study (from either grid point or pit soils). The Nard series description also contains an E/Bt horizon and Btx1 and Btx2 horizons (NRCS 2002). The soils from this research can have high bulk densities, however no brittle or cemented fragipan horizons were found, nor E/Bt horizons. The Shaser soil series description states the horizon progression, Oi, E, Bw1, Bw2, 2Bt1, 2Bt2, 2C (NRCS 2002). Even ignoring the presence of an E horizon, this sequence of horizons does not exist in any of the soil pits dug for this study. It is, therefore, unlikely that the Nard, and Shaser soils occur on the study site as currently mapped.

The Blag, Blewett, and Brisky soils are similar in horizon type and depth to the soils found on the study site. Two differences are: the Blewett series is found at higher elevations with darker soil colors, and the parent material of the Blag series is composed of residuum and colluvium, and the lacks volcanic ash and loess deposits common in the Blewett and Brisky (Soil Survey Staff 1995, NRCS 2002). However, these three series have coarse textures in common. Gravelly sandy loam, very gravelly sandy loam, and extremely gravelly sandy loam textures are described in the Blag, Blewett and Brisky (NRCS 2002). However, the Blag series can contain only 5 % rock fragments. Only two occurrences of gravelly textures were described in the soil pits, gravelly loam and gravelly clay loam, and greater amounts of gravel, to require a very or extremely gravelly texture, were not found. The difference in gravel content between the mapped soil and soil pit results make the presence of the Blewett and Brisky series on the study site questionable. Blag soils are possible with low percent rock fragments.

It is also unlikely that the Dinkelman occurs on the study plots because it forms from granodiorite (NRCS 2002), which is not present on this site (Tabor et al. 1982). Also the Dinkelman description states the presence of gravel in this soil, with gravelly sandy loam textures in the mineral horizons (Soil Survey Staff 1995). As stated above, neither this texture nor consistent gravel content was found in the soil from this research. Given the inconsistencies in parent material and texture between this series and the current study's findings, it is unlikely that the Dinkelman is present on the study sites.

However, the Borland, Blag (with low percent rock fragments), Cle Elum (when the E horizon is absent), Varelum and Yaxing are similar to the soils this study found, and are likely on the study site. The parent materials of these soils, combinations of sandstone colluvium and residuum, volcanic ash, and loess depending on the series (Soil Survey Staff 1995), are the same parent materials found on the study site. The Borland, Cle Elum, Varelum, and Yaxing contain loam and clay loam textures and horizonation progression, containing Bt horizons, similar to this study's results (Soil Survey Staff 1995, NRCS 2002). Shallow soils found on the site are similar to the Blag series in soil depth and horizon type and depth. The soils from this study have not been taxonomically keyed, so specific series cannot be matched.

SOIL TYPES

Forty-eight soil pits were dug over the entire study area, four from each of twelve sites. These soils were sorted into eight major soil types based on horizonation (Figure 4.1). Profiles with similar horizons from different sampled soil pits were grouped together (e.g., A2 and AB), and not all horizons were present in every soil sampled (see Figure 4.1 or Appendix A). Soils were grouped together based on the general progression of horizons. Two of these soil types were outliers and contain only one sampled soil pit (Soils 7 and 8). One soil type, Soil 2, included only two sampled soil pits. Therefore, the majority (44) of the soils sampled in the study area are described by Soils 1, 3, 4, 5, and 6. Given the range in topographic and vegetative factors it is somewhat surprising that the majority of the soils can be summarized with only five soil descriptions (Appendix A).

It should be noted that Figure 4.1 represents approximate horizon thickness. Within each soil type, some horizons may not have been present in every sampled soil pit (in blue text). The thickness displayed for these horizons is an average of the thicknesses recorded in the field. Therefore, where a horizon was absent, no value was averaged. This is in contrast to Tables 4.1-4.8 (discussed later) that displays average thickness by including zero values for thickness where horizons were absent.

The eight soil types can be further grouped by level of development. Soils 1 and 2 show the least development with a shallow depth and a moderately thin A horizon (Soil 2), or no A horizon at all (Soil 1). Comparing the two, Soil 2 displays more horizon development with the presence of an A horizon, where as Soil 1 shows less development, but a slight increase in depth. Soils 5 and 6 demonstrate slightly more development, with Bw and Bw2 horizons possible, than Soils 1 and 2. Soil 5 seems to be the more mature of the two, exhibiting a second A horizon or transition AB horizon and, on average, is deeper than Soil 6. Soils 3 and 4 show the greatest development of all eight soil types.

Both soil types 3 and 4 contain at least one Bt horizon, and many of the sampled soils within soil types 3 and 4 exhibited multiple Bt horizons. The differences between these soils lies in the presence of A2, AB, and/or BA horizons in Soil 4 that do not exist in Soil 3. Also, on average, Soil 4 is deeper than Soil 3. Soil 4 is closest of all eight soil types to the Borland, Varelum and Yaxing series' described above. Soil 7 includes one sampled soil pit that required a separate category because of a buried horizon and the presence of ash found from the A1 to the C horizon. Soil 8 also includes one sampled soil with a buried horizon, however the small amount of ash present in this profile required an additional, eighth category.

Within the eight soil types, great variability is apparent in depth and horizon types. Soil depths range from 10 cm to 132 cm (Tables 4.1-4.8). Soils contain from one to six mineral horizons (Figure 4.1). O horizons, may be discontinuous, but are always present. A horizons are present in all soil types except Soil 1. B horizons vary, with Bw horizons evident in four of the eight soil types, Bw2 horizons possible in two of eight types, and Bt horizons and possibly Bt2 horizons present in two of the eight soil types.

PROPERTIES OF SOIL TYPES

Tables 4.1-4.8 detail some qualities of the soil types. Note that within a soil type, the range in thickness for some horizons begins with zero. These horizons were not present in every soil pit sampled. In this case, where a horizon was absent, a zero value was entered. The zero values were also used in calculating the horizon mean thickness. For example, in Soil 1, three of the five soils contain Bw horizons. In the other two sampled soils in Soil 1, a Bw horizon was absent. Therefore, the Soil 1 mean Bw thickness is an average of the three Bw values and two zero values. This is compared to Figure 4.1 that calculates average thickness by excluding a thickness value for absent horizons.

Also note the range in thickness for the last horizon in each table contains two sets of numbers. The first set is the range in thickness. However, since, in most cases the last horizon was a C or R horizon, the end of the horizon was not reached. Therefore the second set of numbers is the range in depth, from the mineral soil surface to the top of the last horizon (usually C or R). Mean thickness in these horizons is portrayed in this way as well. The ranges in the last horizon of each soil type, or total soil depth, demonstrate different degrees of variability. This variability does not seem to be related to the number of samples or amount of horizons within the soil type.

Tables 4.1-4.8 also show all the moist colors, textures and structures found in each horizon of the sampled soils. Generally the variability of these properties increases with number of soils included in the soil type. Most of the soils have a hue of 10 YR, however a few 2.5 Y and 7.5 and 5 YR colors are also present. Textures range from sand to silt to silty clay, although the most common textures are loam, loamy sand, sandy loam, sandy clay loam, and clay loam. Structures are variable, including granular, sub-angular blocky, angular blocky, platy, prismatic, and massive. However, granular, sub-angular blocky and angular block are dominant. Only one occurrence of a platy structure occurred due to the layering and flaking of decomposing sandstone. A massive structure was also present only once due to an R sandstone layer. Prismatic structure was present in only four horizons over three profiles. Bulk density ranges and averages (Tables 4.1-4.8) generally increase with depth, however overall variability is slight. Some horizon bulk densities can be quite high especially with proximity to a C or R horizon. This is evident in the A horizon of Soil 2, the Bt1, Bt2, and Bt3 horizons in Soil 3, the BC, BCr, or BCt horizons in Soil 4, and Bw1 and Bw2 horizons in Soil 6. Soils 7 and 8 contain only one sampled soil each; therefore data about these soil types is limited.

SITE VARIABILITY BY SOIL TYPE

Topographic and vegetative factors are highly variable within soil types (Table 4.9). Soils 2, 7, and 8 show little variability due to a low sample size (n=2 and 1). Ranges for the vegetative factors on Soils 7 and 8 are the minimum and maximum range for the field category recorded (refer to Chapter 3, Field Methods). Soils 3, 4 and 6 exhibit landscape and vegetative variability that encompass nearly the entire range for the study site (Table 4.9 and Chapter 3, Site Description). Soils 1 and 5 show similar and slightly less variability in landscape and vegetative characteristics. Further patterns with soil type and landscape or vegetation are not evident due to the large variability. Figures 4.2-4.9 demonstrate the landscape and vegetation variability with the associated soil types.

SOIL VARIABILTY

Horizon thickness variability is extensive in Soils 1, 3, 4, 5, and 6 (Figures 4.10-4.12). Soils 2 and 7 demonstrate little variability in horizons due to a low number of samples (2 and 1, respectively), however Soil 7 does include variability of horizon thickness within the profile. (Soil 8 shows no variability because data were not taken on range in horizon thickness for the one soil comprising Soil 8.) The remaining soil types have large variation in horizon thickness, especially in transition horizons (ABs and BAs) and B horizons. Soils 4, 5, and 6 also show a large variability in the BC, C, BCr or BCt horizon. These results demonstrate that the soils within each category, 1-8, are moderately associated. The goal of grouping the soils into these categories is to investigate the similarities and variability and simplify comparisons of the soil with the environment.

MODELING HORIZON THICKNESS

Describing the soil, by soil type, as shown above, works well to compare entire soil profiles. However, due to the wide ranges in vegetation cover, slope percent, aspect, slope position, erosion, and soil horizon thickness associated with each soil type (Tables 4.1-4.9), and low sample size within some of the soil types, no statistically significant results were evident from the soil profile data. Thus, all the profile data were used to derive models for each horizon thickness.

O, A, Bw horizon thickness, and depth to the C horizon were found to be significantly associated with aspect, erosion, tree canopy cover, grass cover, and herbaceous cover using linear regressions. O horizon thickness is predicted by aspect, erosion, percent tree canopy cover, and percent grass cover:

$$\text{O horizon thickness (cm)} = 3.41 - 0.57(\text{ASP}) - 0.04(\text{EROS}) + 0.025(\text{TREES}) + 0.022(\text{GRASS}) \quad (4.1)$$

$$P = 0.003 \qquad R^2 = 0.412 \qquad n = 48$$

where ASP = aspect, EROS = percent erosion, TREES = percent tree canopy, and GRASS = percent grass cover. The significance of each variable is 0.121 for aspect, 0.041 for erosion, 0.053 for canopy cover, and 0.079 for grass cover. All four variables are categorical (see Chapter 3, Field Methods). These variables are understandable ecologically, as tree and grass cover contribute to the O horizon and erosion reduces O horizon thickness. Aspect is significant because on dry south slopes vegetation is less dense than on moister north slopes. Therefore south slopes will have less vegetation to contribute to an O horizon. There may be statistical interactions within this model.

Two models showed significance with A horizon thickness:

$$\text{A horizon thickness (cm)} = 10.11 - 0.46(\text{HERBS}) + 0.29(\text{GRASS}) \quad (4.2)$$

$$P = 0.007 \qquad R^2 = 0.311 \qquad n = 48$$

$$\text{A horizon thickness (cm)} = 13.41 + 0.26(\text{GRASS}) - 0.42(\text{HERBS}) - 0.28(\text{EROS}) \quad (4.3)$$

$$P = 0.010 \qquad \text{adjusted } R^2 = 0.274 \qquad n = 48$$

where HERBS = percent herbaceous cover, GRASS = percent grass cover, and EROS = percent erosion. Equation 4.2 variables are significant at the 0 .019 (HERBS), and 0.009 (GRASS) levels. In equation 4.3 the significance of each variable is 0.032 (HERBS), 0.023 (GRASS), and 0.227 (EROS). All the variables are categorical (see Chapter 3, Field Methods). These results suggest that erosion may be correlated with A horizon thickness, but not as strongly as grass and herbaceous cover. On the landscape, grasses contribute to the A horizon through organic matter inputs from roots and erosion subtracts from the A horizon thickness. The model suggests that as herbaceous cover becomes more dense, thinner A horizons result. This may be explained by reduced grass cover and fine root input where higher herbaceous covers occur. Therefore, herbaceous species could account for less fine root matter to turnover and less organic matter being contributed to the A horizon.

Models for the Bw horizon and depth to the C horizon were also developed. A significant model for Bt horizon thickness could not be generated. Environmental factors are undoubtedly influencing the Bt horizon, however none of the variable data showed significance. All the variables are categorical in the following models (see Chapter 3, Field Methods). The equation for Bw thickness is:

$$\text{Bw horizon thickness (cm)} = 44.75-0.48(\text{EROS}) \tag{4.4}$$

$$P = 0.041 \qquad R^2 = 0.386 \qquad n = 48$$

where EROS = percent erosion. Clearly more environmental factors contribute to the present and thickness of Bw horizons, however erosion was the only significant variable from this data set. It is understandable why erosion is correlated with Bw thickness, especially on steep slopes, where erosion events can remove a large amount of soil. However it is unclear as to why topographic and vegetative factors are not correlated with Bw or Bt horizon thickness. Perhaps the age of these horizons makes accurately measuring significant variables difficult.

The model for depth to the C horizon is easier to interpret.

$$\text{Depth to C horizon (cm)} = 44.28 - 0.55(\text{EROS}) + 0.42(\text{GRASS}) \quad (4.5)$$

$P = 0.000 \quad R^2 = 0.408 \quad n = 48$

where EROS = percent erosion and GRASS = percent grass cover. The significance of the variables is 0.018 (EROS) and 0.006 (GRASS). Grass cover is contributing to soil depth and erosion decreases soil depth. One reason grass could be increasing the depth to the C horizon is due to increased A horizon development from root turnover added organic matter to the soil.

The study site exhibits highly variable topography and young, middle-aged and old soils. Given the time frame of vegetation impacts on the soil relative to topographic influences, topographic factors were expected to influence soil horizon thicknesses to a greater extent. However, aspect is only included in the model for O horizon thickness, and slope and slope position were not significant in any of the regression models. This differs from all the literature previously discussed, where usually topographic position varies with soil or horizon depth. Figure 4.13 portrays the distribution of soil horizon thicknesses with slope position. Although O horizons are shallower on ridges than backslopes or valleys and Bw's are thickest in valleys, the differences between horizon thicknesses are not significantly different between all three slope positions (Tukey's test was used to compare differences in means).

This contrasts to the work discussed previously by Roché and Busacca (1987), where the soil type and the landscape determined vegetation type. In the Wenatchee

Mountain research, the O and A horizon thickness appears determined by the vegetation, and topography seems relatively insignificant. Also in this study, vegetation only contributes to soil horizon thicknesses; vegetation type and percent cover are not significant on soil type.

Although the native vegetation of the study site has not significantly changed, as in research by Amiotti et al. (2000), the significance of vegetation may be similar in these two studies. In Amiotti et al. (2000) it was noted that the introduction of trees into native grassland caused significant soil changes near the tree. In this study of the Wenatchee Mountains, it is likely that the patchy distribution of vegetation types contributes to distinction between different soil areas, similar to Ryan and McGarity (1983). It is possible that soil processes differ between these areas and show some similarities within vegetation patches, such as horizon thickness. For example, increased fine root turnover under grass patches leading to thicker A horizons. However, due to additional variables contributing to soil morphology, vegetation is not significant when examining soil type (Soils 1-8).

Aspect was the only significant topography variable in the models. Marron and Popenoe (1986) also found that north aspects contributed to soil moisture, which played a role in erosion, causing slower rates of erosion on north slopes, thus having greater soil development. However, in this study, aspect was significant only in modeling O horizon thickness. If increased soil moisture reduces erosion on the north aspects of this study site, causing increased development, aspect should be significant in the mineral soil models also. Even though aspect is not significant in the models for mineral soil thickness, the processes discussed by Marron and Popenoe (1986) cannot be discounted in the Wenatchee Mountains. Aspect may not be a significant factor because other factors, such as ashfall, may be contributing to soil horizon thickness and interfering with the effects from aspect. One reason aspect may affect O horizon thickness is that soil moisture may be impacting vegetation production, to increase litterfall and O horizon thickness.

All of the equations shown above are significant, however they are not complete models. Other unmeasured factors in this study are likely to effect soil horizon thickness. In this case the completeness and accuracy of the data may be limiting the results (Phillips et al. 1996). Due to the complex topography and history of disturbance on the study sites, it is difficult to account for, or even realize, all the factors affecting the study site. The O horizon model may be the most accurate because it can be more easily measured and modeled. Factors that contribute to the O horizon, like litterfall and decomposition, operate on shorter time scales that can be observed and recorded. However, the mineral soil, requiring more time for development, has been influenced by environmental factors that may no longer be present. Some variables and the ways in which they impact the soil are likely to have changed over time. Therefore, current variable measurements may not accurately depict how past conditions have influenced the current soil. For these reasons, the next chapter will apply these models to the grid point data to determine the model reliability and predictability.

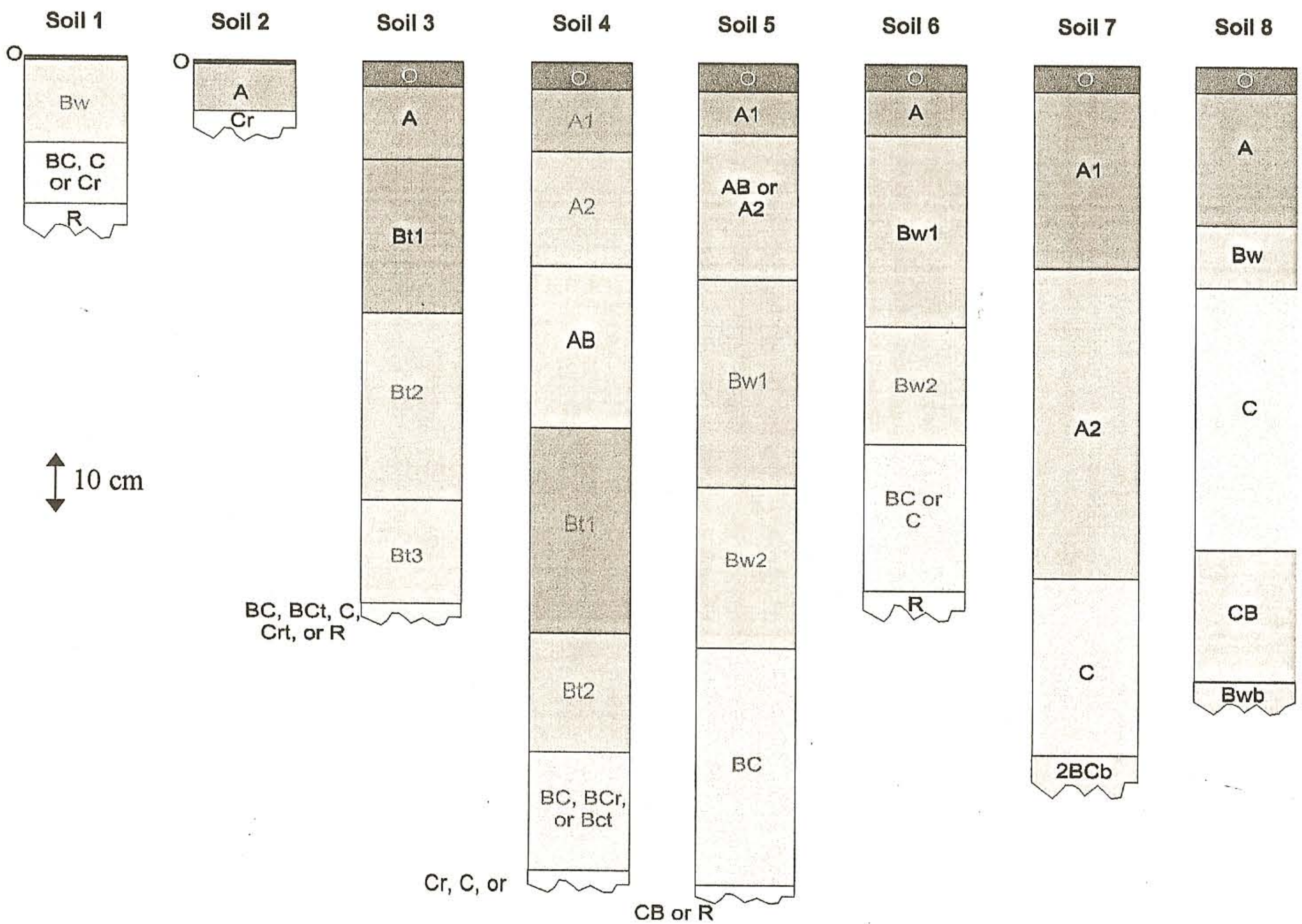
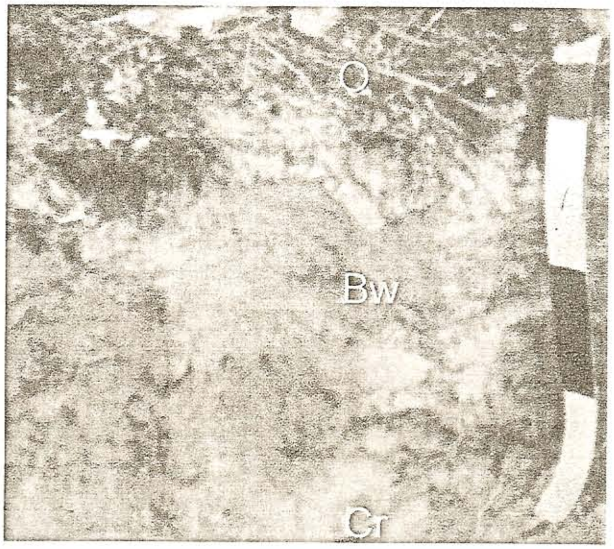


Figure 4.1. Soil types found on the study site based on horizonation. Blue text symbolizes horizons that are not present in every sampled soil pit. Horizon and soil thickness are approximately to scale based on average thickness in the field (zero values are not averaged into the horizon thickness for absent horizons). Represented colors are not accurate field colors. For detailed soil descriptions see Appendix A.



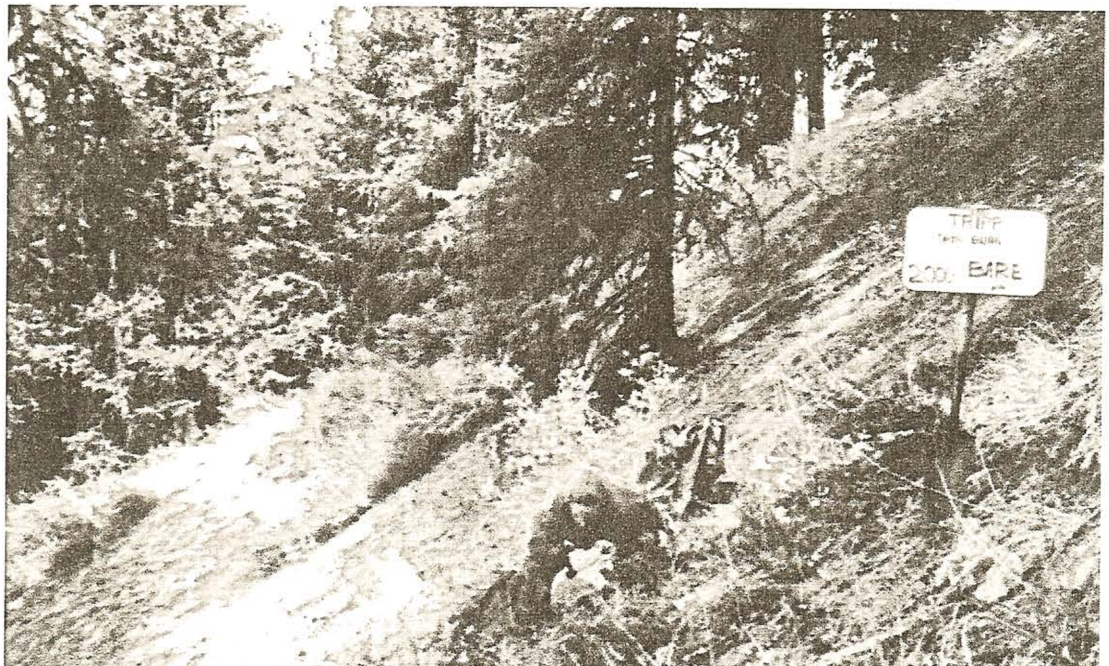
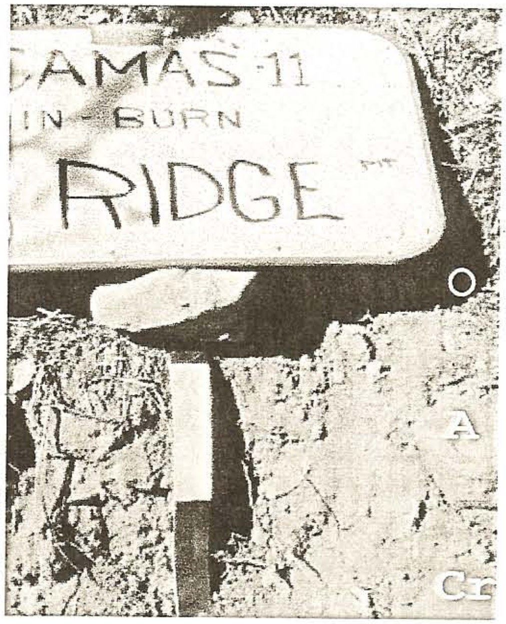


Figure 4.2. Example of Soil 1 and associated landscape. The yellow and black tape in the soil pit is in increments of 10 cm.



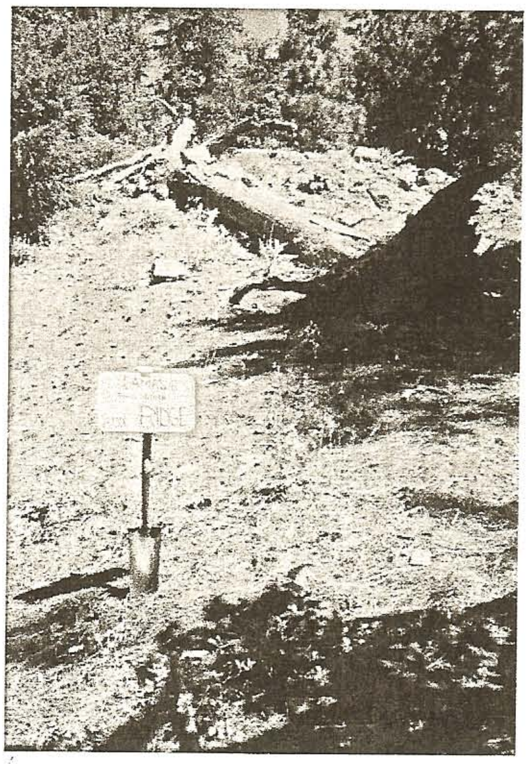
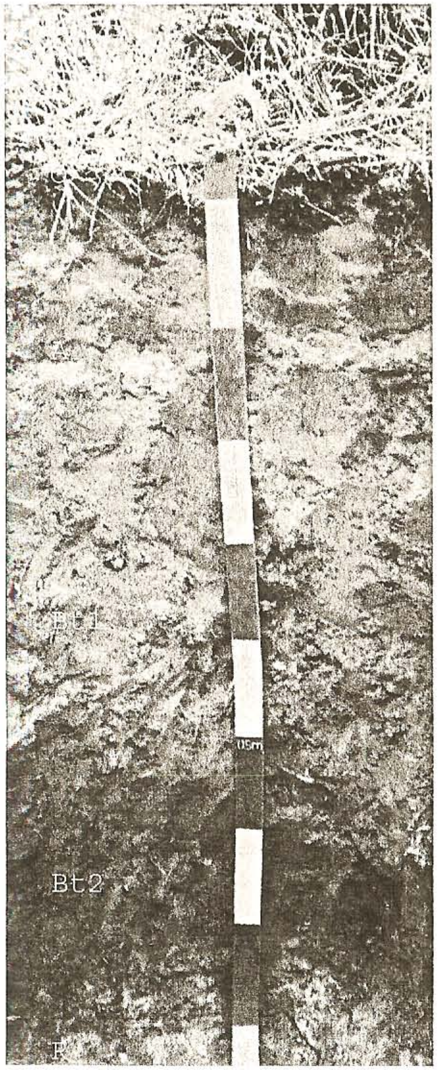


Figure 4.3. Example of Soil 2 and associated landscape. The yellow and black tape in the soil pit is in increments of 10 cm.



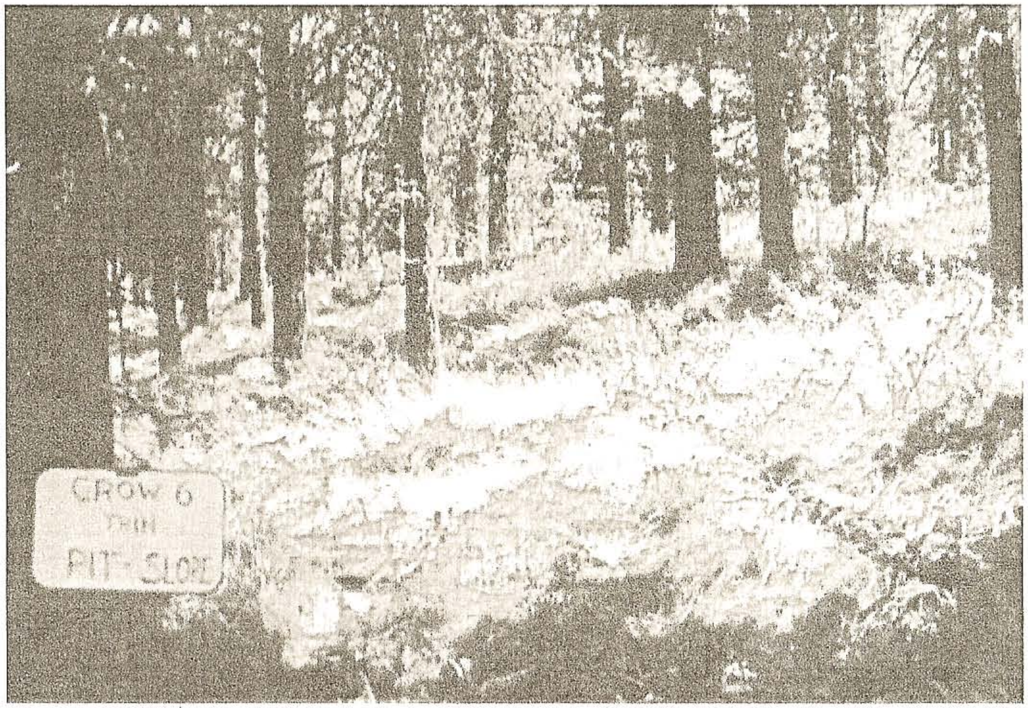


Figure 4.4. Example of Soil 3 and associated landscape. The yellow and black tape in the soil pit is in increments of 10 cm.

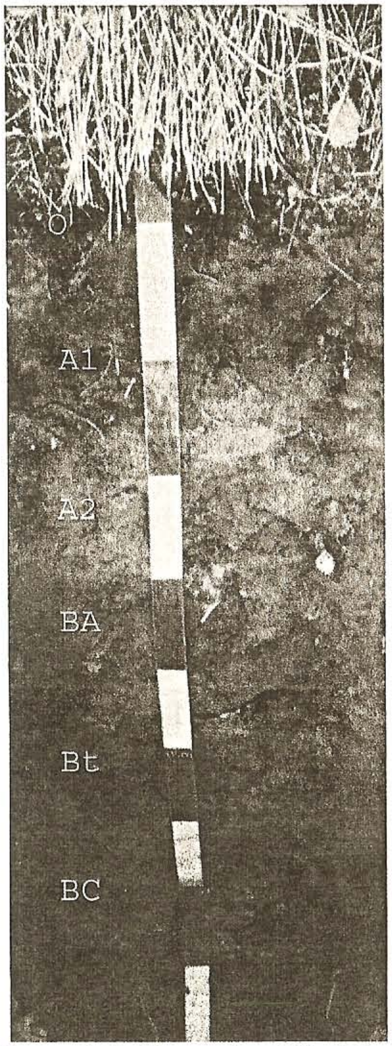


Figure 4.5. Example of Soil 4 and associated landscape. The yellow and black tape in the soil pit is in increments of 10 cm.

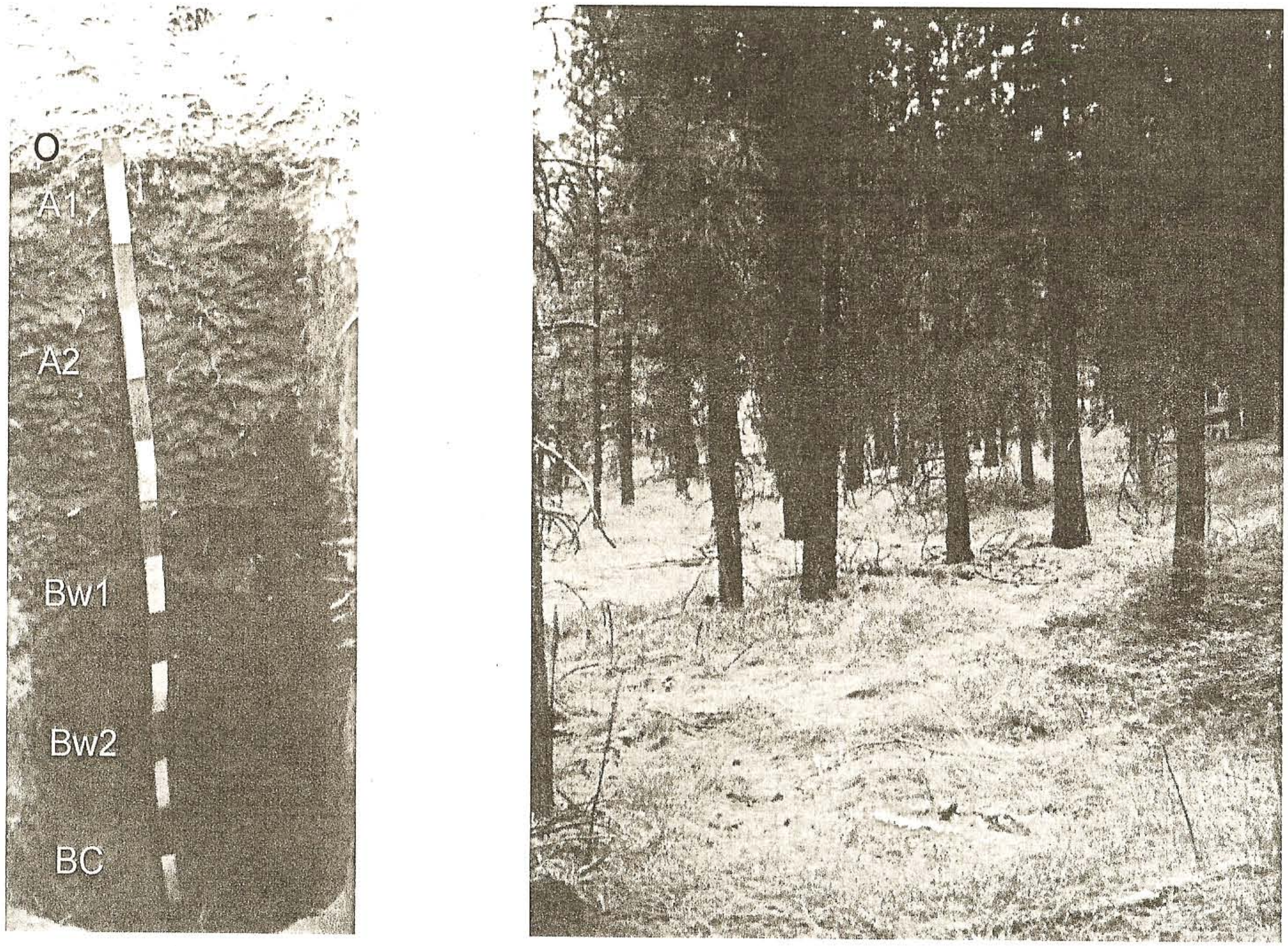


Figure 4.6. Example of Soil 5 and associated landscape. The yellow and black tape in the soil pit is in increments of 10 cm.

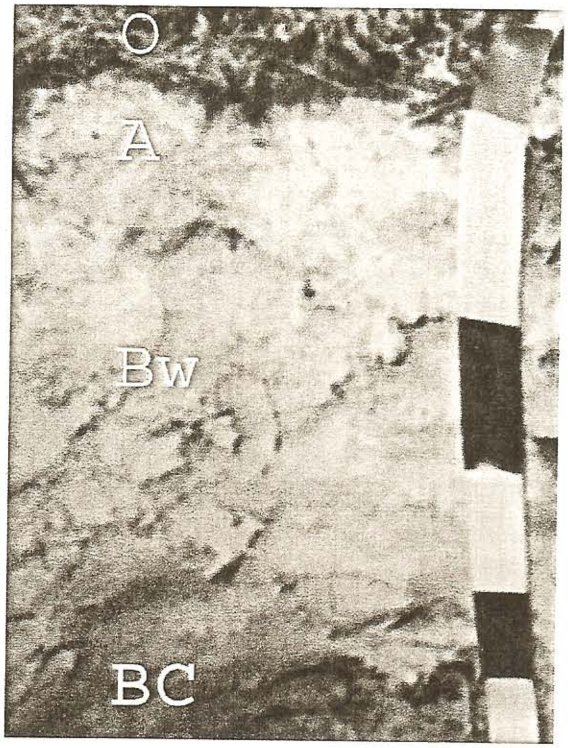


Figure 4.7. Example of Soil 6 and associated landscape. The yellow and black tape in the soil pit is in increments of 10 cm.

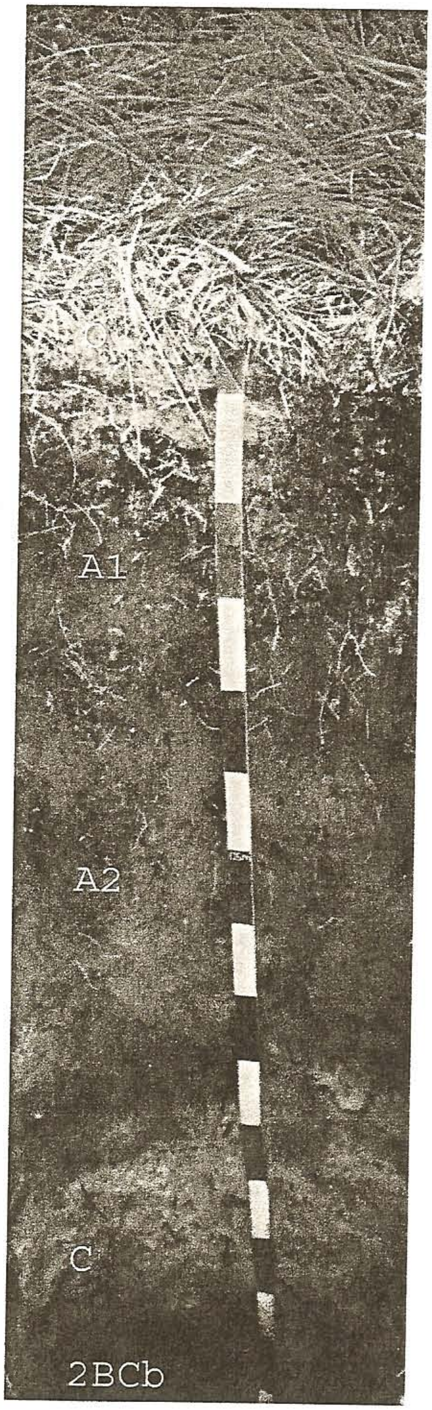
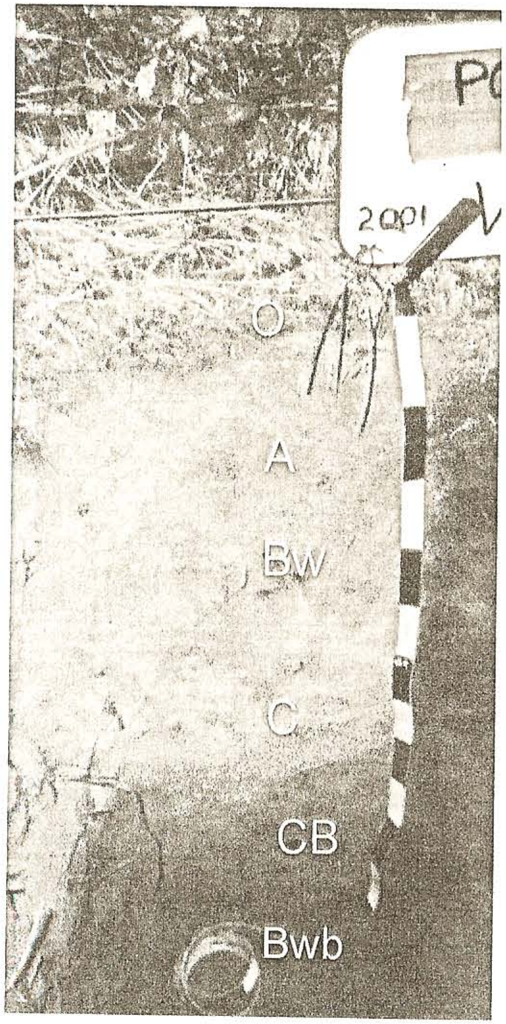


Figure 4.8. Example of Soil 7. The yellow and black tape in the soil pit is in increments of 10 cm. An example of the landscape for Soil 7 was not available.



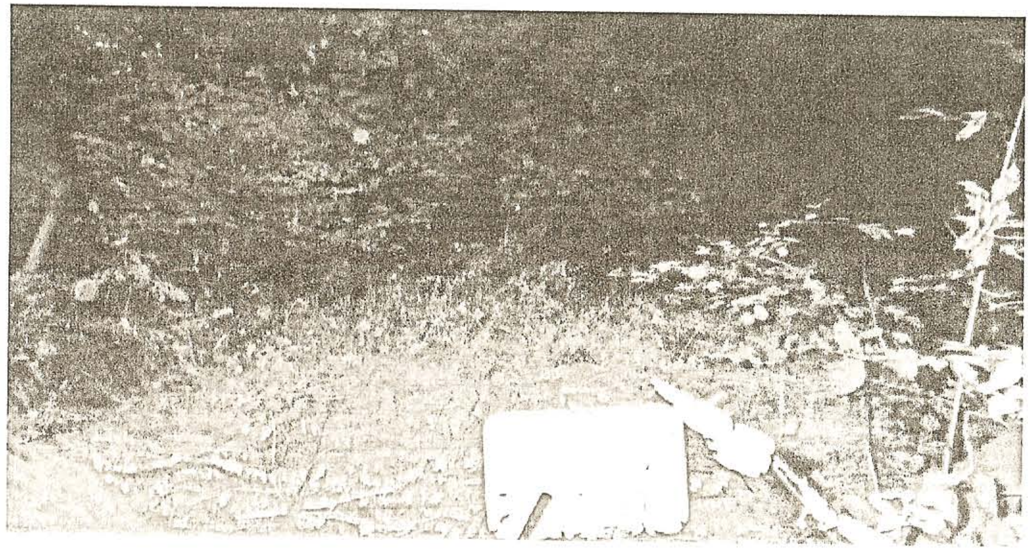


Figure 4.9. Example of Soil 8 and associated landscape. The yellow and black tape in the soil pit is in increments of 10 cm.

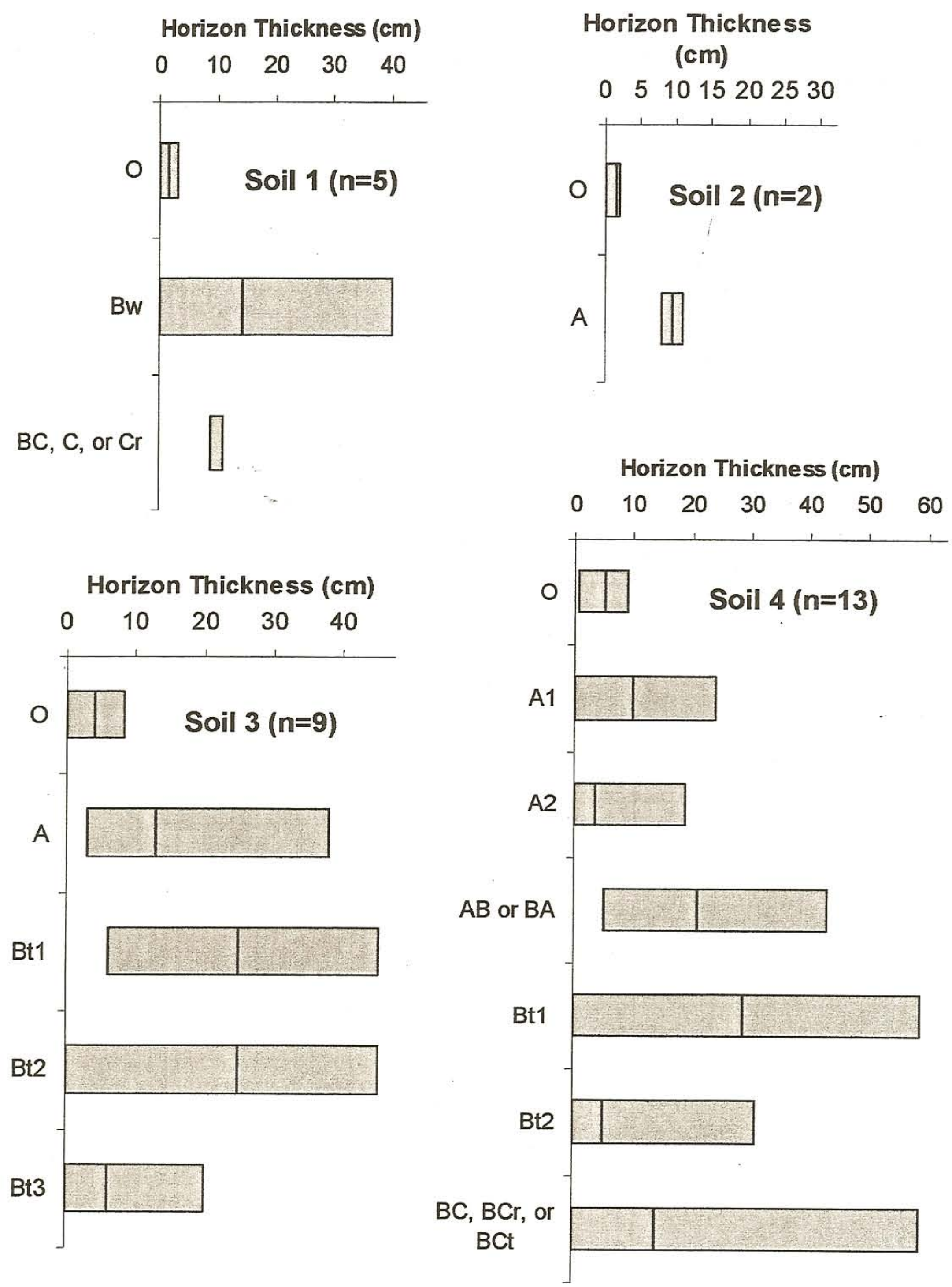
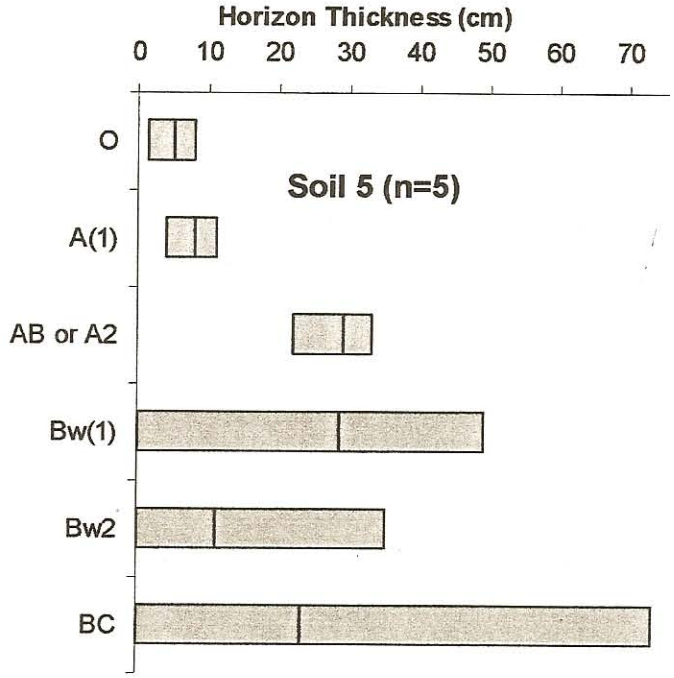


Figure 4.10. Variability of horizon thickness in Soils 1-4. The black line represents the mean thickness. The bar represents the minimum and maximum thickness found in the field.



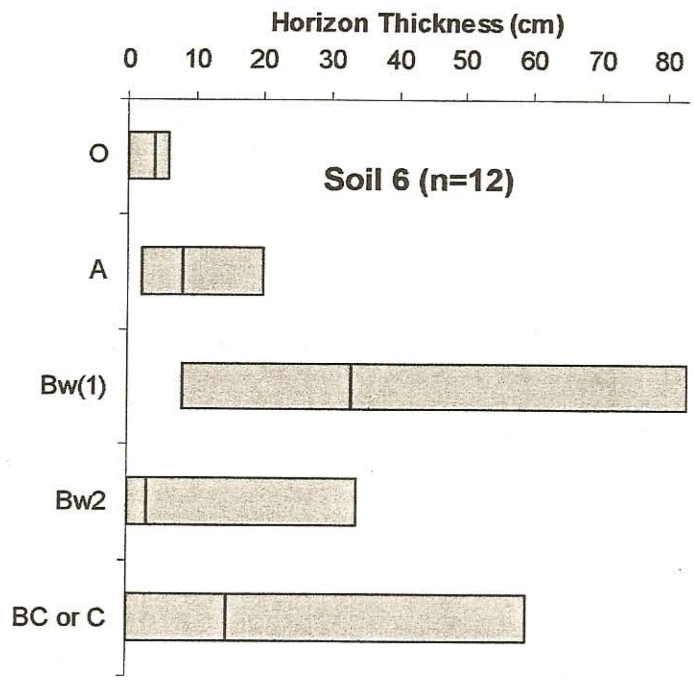


Figure 4.11. Variability of horizon thickness in Soils 5-6. The black line represents the mean thickness. The bar represents the minimum and maximum thickness found in the field.

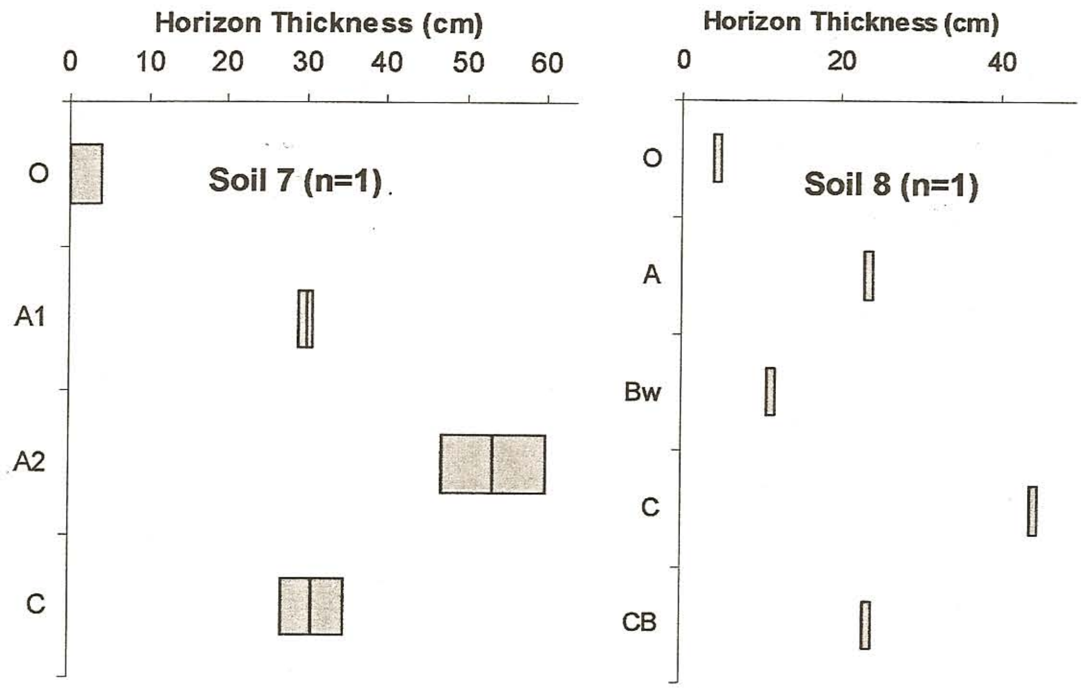


Figure 4.12. Variability of horizon thickness in Soils 7-8. The black line represents the mean thickness. The bar represents the minimum and maximum thickness found in the field. Soil 7 shows horizon thickness variability from within the one soil profile in that soil type. Soil 8 indicates only horizon thickness. No variability data were available for the single profile that comprises Soil 8.

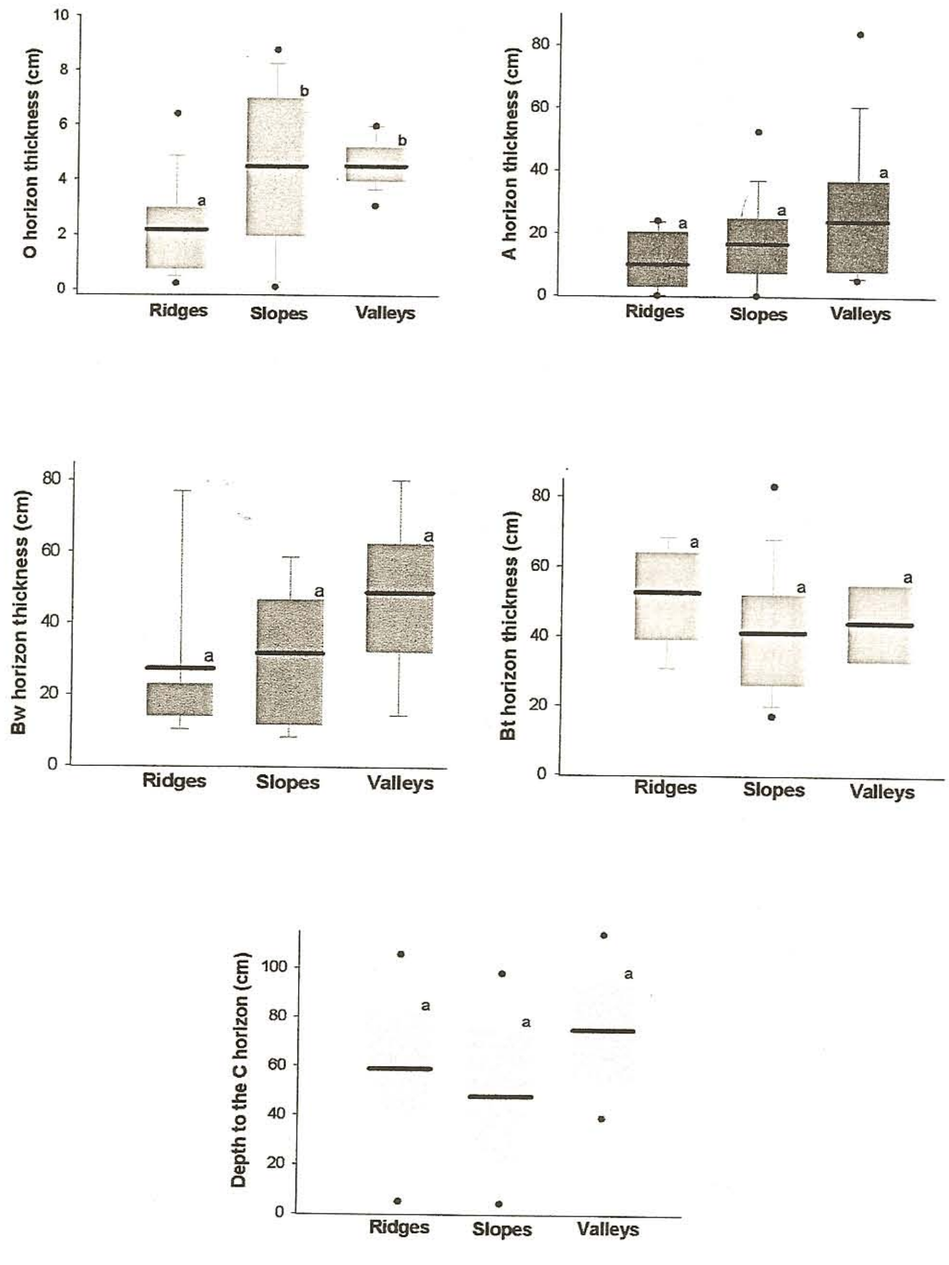


Figure 4.13. Horizon thickness distributions by slope position. The colored boxes show the range in horizon. The black line indicates the mean, errors bars show 5% and 95% confidence intervals, and dots represent outliers. The letters indicate groups of significantly different means at the 0.05 level. Only O horizon showed a significance difference between the ridges and the other two slope posititions. None of the horizons showed significant differences between all three slope positions.

Table 4.1. Soil 1-soil properties. Five sampled soil pits are included in soil type 1 (n=5).

Horizon Type	Range in Thickness (cm)	Mean Thickness (cm)	Moist Color	Texture	Structure	Bulk Density Range/Mean (g/cm^3)
O	0.1-3	1.5	-	-	-	0.0-0.1 0.1
Bw	0-40	14.5	2.5 Y 3/2, 10 YR 4/2, 10 YR 4/3	loamy sand, sandy loam	1f gr, 1m gr, 2m abk	1.1-1.3 1.2
BC, C, or Cr	9-11	11	2.5 Y 4/3, 2.5 Y 6/2, 10 YR 4/3, 10 YR 5/6	sandy loam, sand, rock	0f gr, 0vf gr, 1f gr, 3c abk	1.1-1.4 1.2
R	1-5+ *11-51 (depth from mineral surface)*	2.5 *24 (depth from mineral surface)*	-	-	massive	-

Table 4.2. Soil 2-soil properties. Two sampled soil pits are included in soil type 2 (n=2).

Horizon Type	Range in Thickness (cm)	Mean Thickness (cm)	Moist Color	Texture	Structure	Bulk Density Range/Mean (g/cm^3)
O	discontinuous-2	1.5	-	-	-	0.0-0.1 0.1
A	8-11	9.5	10 YR 3/2, 10YR 3/3	sandy loam	1f gr, 1m sbk	1.4-1.6 1.5
Cr	5-7+ *8-11 (depth from mineral surface)*	6 *9.5 (depth from mineral surface)*	10 YR 3/3, 10 YR 3/4	sand	1m gr, rock	-

Table 4.3. Soil 3-soil properties. Nine sampled soil pits are included in soil type 3 (n=9).

Horizon Type	Range in Thickness (cm)	Mean Thickness (cm)	Moist Color	Texture	Structure	Bulk Density Range/Mean (g/cm^3)
O	discontinuous-8.5	4	-	-	-	0.0-0.1 0.1
A	3-38	13	10 YR 3/1, 10 YR 3/2, 10 YR 3/3, 10 YR 3/4, 10 YR 4/2, 10 YR 4/4, 7.5 YR 4/3	sandy loam, sandy clay loam, loam, gravelly loam	1f gr, 1m gr, 3m gr, 1f sbk, 2f sbk, 1m sbk, 2m sbk	1.0-1.4 1.2
Bt(1)	6-46	25	10 YR 4/3, 10 YR 4/4, 10 YR 5/4, 7.5 YR 4/3, 7.5 YR 4/6, 5 YR 4/4	sandy clay loam, loam, clay loam	1f gr, 2m sbk, 3m sbk, 2c sbk, 2m abk, 3m abk	1.2-1.6 1.4
Bt2	0-45	25	10 YR 3/6, 10 YR 4/4, 10 YR 5/3, 10 YR 5/4, 10 YR 5/6, 7.5 YR 3/3	clay loam, sandy clay loam	3c abk, 2m abk, 1m sbk, 3m sbk, 2c sbk	1.2-1.6 1.4
Bt3	0-20	6	10 YR 5/4, 7.5 YR 4/4, 7.5 YR 4/6	clay loam, gravelly clay loam	3m sbk, 2m sbk, 2c sbk	1.5-1.6 1.6
BC, BCt, C, Crt, or R	1-19+ *30-91 (depth from mineral surface)*	8 *71 (depth from mineral surface)*	10 YR 4/6, 10 YR 5/4, 10 YR 5/6	sandy clay loam, sandy clay, sand	1f gr, 3m abk, 2m sbk, 3m pl	1.3-1.9 1.8

Table 4.4. Soil 4-soil properties. Thirteen sampled soil pits are included in soil type 4 (n=13).

Horizon Type	Range in Thickness (cm)	Mean Thickness (cm)	Moist Color	Texture	Structure	Bulk Density Range/Mean (g/cm^3)
O	0.5-9	5	-	-	-	0.0-0.3 0.1
A(1)	0-24	10	2.5 Y 2.5/1, 2.5 Y 4/2, 10 YR 3/1, 10 YR 3/2, 10 YR 5/3	sandy loam, loam, sandy clay loam	0f gr, 1f gr, 2f gr, 1m gr, 2m gr, 1vc gr, 1m sbk, 2m sbk, 2c sbk	0.9-1.3 1.1
A2	0-19	3.5	10 YR 3/2	sandy clay loam, loam	2m sbk, 3c sbk	1.0-1.4 1.2
AB or BA	5-47	21	2.5 Y 3/2, 10 YR 3/2, 10 YR 3/3, 10 YR 4/2, 10 YR 4/3, 10 YR 5/4, 7.5 YR 3/3	sandy clay loam, sandy loam, clay loam, loam	1m sbk, 2m sbk, 3c sbk, 2c abk, 3c abk, 3f pr	1.0-1.3 1.2
Bt(1)	0- 59	29	2.5 Y 4/3, 2.5 Y 5/4, 10 YR 4/3, 10 YR 4/4, 10 YR 5/4, 7.5 YR 4/3, 7.5 YR 4/4	clay loam, silty clay, sandy clay loam,	2m sbk, 3m sbk, 3c sbk, 3vc sbk, 2c abk	1.2-1.5 1.4
Bt2	0-31	5	2.5 Y 5/6, 10 YR 6/4, 7.5 YR 4/6	silty clay, sandy clay loam	1m sbk, 2m sbk	1.1-1.4 1.2
BC, BCr, or BCt	0 - >59	14	2.5 Y 4/4, 10 YR 3/3, 10 YR 4/3, 10 YR 5/4, 10 YR 5/6	clay loam, sandy clay loam	2m sbk, 3m sbk, 3c sbk, 3c abk	1.3-1.6 1.4
C, Cr, or R	1-7+ *34-99 (depth from mineral surface)*	7 *64 (depth from mineral surface)*	2.5 Y 4/4, 10 YR 5/6, 10 YR 7/4	sandy clay loam, rock	1f gr, 3m sbk, 3vc abk	-

Table 4.5. Soil 5-soil properties. Five sampled soil pits are included in soil type 5 (n=5).

Horizon Type	Range in Thickness (cm)	Mean Thickness (cm)	Moist Color	Texture	Structure	Bulk Density Range/Mean (g/cm^3)
O	1.5-8	5	-	-	-	0.0-0.1 0.1
A(1)	4-11	8	10 YR 3/1, 10 YR 3/2, 10 YR 3/3, 10 YR 4/3	sandy loam, sand, loam, silty clay loam	1f gr, 1m gr, 1m sbk, 2m sbk	0.9-1.3 1.1
AB or A2	22-33	29	10 YR 2/1, 10 YR 3/2, 10 YR 4/1, 10 YR 4/3	sandy loam, loamy sand, loam, silty clay loam	1m sbk, 2m sbk, 2c sbk	1.1-1.3 1.2
Bw(1)	0-49	28.5	2.5 Y 4/3, 10 YR 3/4, 10 YR 4/2, 10 YR 4/3	loamy sand, silty loam, silty clay loam	1m sbk, 2m sbk, 2c sbk	1.2-1.3 1.3
Bw2	0 - >35	11	2.5 Y 5/4, 10 YR 3/3	loamy sand	1vc bk, 2m pr	1.3-1.4 1.4
BC	0 - >73	23	10 YR 4/3, 10 YR 4/6, 10 YR 5/4	loamy sand, sandy clay loam	0f gr, 2vc bk, 2m pr	1.3-1.4 1.3
CB or R	1-18+ *81-132 (depth from mineral surface)*	6.5 *99 (depth from mineral surface)*	2.5 Y 3/3	loamy sand, rock	2m sbk	1.3 1.3

Table 4.6. Soil 6-soil properties. Twelve sampled soil pits are included in soil type 6 (n=12).

Horizon Type	Range in Thickness (cm)	Mean Thickness (cm)	Moist Color	Texture	Structure	Bulk Density Range/Mean (g/cm^3)
O	discontinuous-6	4	-	-	-	0.0-0.1 0.1
A	2-20	8	2.5 Y 4/2, 10 YR 2/2, 10 YR 3/1, 10 YR 3/2, 10 YR 3/4, 10 YR 4/3, 10 YR 5/2	loam, sandy clay loam, loamy sand, sandy loam, silt	1f gr, 1c gr, 2m gr, 1f sbk, 1m sbk, 2m sbk, 2m bk	0.5-1.3 1.1
Bw(1)	8-83	33	2.5 Y 3/3, 2.5 Y 4/3, 2.5 Y 4/4, 10 YR 3/2, 10 YR 3/3, 10 YR 3/4, 10 YR 4/2, 10 YR 4/3, 10 YR 4/4	loam, sandy clay loam, loamy sand, sandy loam	1f gr, 1m gr, 1c gr, 1m sbk, 2m sbk, 3m sbk, 2c sbk	1.1-1.6 1.3
Bw2	0-34	3	10 YR 4/2	sandy loam, sandy clay loam	2m sbk	1.3-1.5 1.4
BC or C	0-59	15	10 YR 3/1, 10 YR 4/3, 10 YR 4/4, 10 YR 4/6, 10 YR 5/4, 10 YR 5/6	sandy clay loam, sandy loam, loamy sand, sand	0f gr, 1f gr, 1m sbk, 2m sbk, 2c sbk	1.2-1.6 1.4
R	1-5+ *19-103 (depth from mineral surface)*	1.5 *42.5 (depth from mineral surface)*	2.5 Y 6/4, 2.5 Y 5/4, 10 YR 6/4	sand, rock	2m sbk	-

Table 4.7. Soil 7-soil properties. One sampled soil pit is included in soil type 7 (n=1).

Horizon Type	Range in Thickness (cm)	Mean Thickness (cm)	Moist Color	Texture	Structure	Bulk Density (g/cm3)
O	-	4	-	-	-	0.1
A1	29-31	30	10 YR 3/3	loam	1f sbk	0.9
A2	47-60	53.5	10 YR 3/4	sandy loam	2m sbk	0.9
C	27-35	31	10 YR 6/4	sandy loam	1f pr	1.2
2BCb	33+ *122 (depth from mineral surface)*	-	2.5 Y 5/6	sandy clay loam	2c sbk	1.4

Table 4.8. Soil 8-soil properties. One sampled soil pit is included in soil type 8 (n=1).

Horizon Type	Range in Thickness (cm)	Mean Thickness (cm)	Moist Color	Texture	Structure	Bulk Density (g/cm^3)
O	4	-	-	-	-	0.1
A	23	-	10 YR 2/1	loamy sand	1f gr	1.1
Bw	11	-	10 YR 3/2	sandy loam	1f gr	1.2
C	44	-	2.5 Y 4/3	sand	0f gr	1.2
CB	23	-	10 YR 3/3	loamy sand	0f gr	1.3
Bwb	17+ *102 (depth from mineral surface)*	-	10 YR 3/2	sandy loam	2m bk	1.3

Table 4.9. Site variability by soil type. Various amounts of ash, colluvium and loess in some soils.

	Slope % Range/Mean	Elevation Range (m)	Aspect	Slope Position	Canopy Cover Range/Mean	Shrub Cover Range/Mean	Forb Cover Range/Mean	Grass Cover Range/Mean	Erosion Area Range/Mean	Parent Material	Sites Found
Soil 1 (n=5)	35-85 57	700-940	north, south, southwest, west, northwest	backslope, ridge	16-60 ~35	16-60 ~35	1-35 ~15	1-60 ~25	0-60 ~25	sandstone	Crow 3, Poison, Sand 19, Slawson, Tripp
Soil 2 (n=2)	25-45 35	1120-1146	south, southwest	backslope, ridge	36-60 ~48	16-35 ~25	1-15 ~8	1-15 ~8	0-15 ~8	sandstone, comglomerate, shale	Camas
Soil 3 (n=9)	0-65 34	695-1146	south, southwest, southeast, west	backslope, ridge, valley	1-85 ~48	1-100 ~48	0-60 ~15	16-100 ~60	0-15 ~8	sandstone, comglomerate, shale	Camas, Crow 1, Crow 6, Ruby, Sand 2, Spromberg
Soil 4 (n=13)	0-70 35	680-1170	west, north, northeast, northwest, south, southeast, southwest	backslope, ridge, valley	0-100 ~35	16-85 ~35	0-85 ~15	16-100 ~60	0-35 ~8	sandstone, comglomerate, shale	Camas, Crow 1, Crow 3, Crow 6, Pendleton, Sand 2, Slawson, Spromberg, Tripp
Soil 5 (n=5)	20-70 40	730-835	west, north, south, southwest	backslope, ridge, valley	0-85 ~25	16-100 ~35	1-35 ~15	36-100 ~48	0-15 ~8	sandstone	Crow 3, Pendleton, Sand 2, Sand 19
Soil 6 (n=12)	5-65 33	730-1160	northeast, south, southwest, west	backslope, ridge, valley	0-100 ~25	1-100 ~48	1-60 ~15	0-100 ~16	0-100 ~8	sandstone, comglomerate, shale	Crow 6, Pendleton, Poison, Ruby, Sand 2, Sand 19, Slawson, Spromberg, Tripp
Soil 7 (n=1)	20	750	southwest	valley	0	1-15	1-15	85-100	0	sandstone	Crow 1
Soil 8 (n=1)	15	730	south	valley	61-85	36-60	0	16-35	unknown	sandstone	Poison

CHAPTER 5: DESCRIPTION AND ANALYSIS OF GRID POINT DATA

SMALL SCALE SITE VARIABILTY

A more detailed discussion of the study site is possible by using the grid point data. As this soil and site data were collected on a small scale (80 m), it encompasses a larger amount of the variability. Tables 5.1-5.5 show differences in slope, vegetation cover, and soil attributes across and within the plots, summarized from the grid point data. Due to the categorical method used to measure the vegetative variables and erosion (see Chapter 3, Field Methods), mean values are shown as the range of the average category for these variables and standard deviations could not be calculated. B horizon thickness is not available at the grid points as soil was dug to only 25 cm, which was not deep enough to consistently reach the bottom of a B horizon. O horizon bulk density was not measured at the grid point locations, therefore this information is not available. Note that the B horizon bulk density numbers are calculated using all B type horizons found, and include Bw1, Bw2, and Bt horizons. Even with this variety of horizon types, B horizon bulk densities are fairly consistent in ranges and means.

Table 5.5 summarizes the overall study area attributes, where the ranges, means and standard deviations are calculated from the mean values of the twelve plots. This table shows a general representation of the Northeastern Wenatchee Mountains area, present within the study site. The data accurately display the area as forested with high grass cover and moderate shrub and herbaceous cover. Surface erosion is evident, yet O and A horizons are moderately thick. Bulk densities are high, probably due to high clay content, despite the presence of ash. However, comparing these values with the ranges and means from the individual plots (Tables 5.1-5.4), it is evident that some plots exhibit values quite different from that of the average area. These differences are discussed below by comparing between plot variability.

Vegetative cover and erosion generally have large ranges for individual plots. This indicates that these factors are highly variable within each plot, undoubtedly due to the existence of vegetation type patches. For example areas with high canopy cover may lack other vegetation types due to competition and shading. Similarly, areas with less canopy cover tend to have high shrub or herbaceous cover and a lower percentage of other vegetation types. Surface erosion is variable but was found in every plot. O and A horizon thicknesses generally have high standard deviation values, implying high variability. Plot Camas and Pendleton show a large range in A horizon bulk density due to O horizon mixing with the A horizon in some areas, causing low bulk densities, and other areas that contain rock fragments in the A horizon, resulting in high bulk densities.

Between plot variability is compared using the mean values. Compared to the other plots, Camas exhibits relatively low grass cover. Crow 1 shows low percent slope and somewhat reduced canopy cover. Also, erosion is lowest on Crow 1 of all twelve plots. Plot Pendleton exhibits a slightly lower percent canopy cover and less steep slopes. Poison shows a low grass cover and high shrub cover. Plot Ruby demonstrates high A and B horizon bulk densities. It is evident that Sand 2 displays the lowest herbaceous cover and the highest erosion of all the plots, except Spromberg. Plot Sand 19 exhibits low shrub cover, high erosion, and thin A horizons. On Slawson, A horizons are always present with narrowly ranging bulk densities. Plot Spromberg displays steep slopes, high erosion, and thin A horizons. Plot Tripp shows steep slopes and thick A horizons. Plots Crow 3, Crow 6 and Slawson are the most representative plots of the entire area (compare Tables 5.1, 5.2, and 5.4 with 5.5).

GIS APPLICATION OF SOIL MODELS

The regression models for soil horizon thickness presented in Chapter 4 were applied to the grid point data to determine the reliability of these models. Significant factors influencing O horizon thickness at the pits are percent grass cover, aspect, percent tree cover, and percent erosion. Two significant equations were found for the A horizon thickness using the pit data. The variables included in these models are percent herbaceous cover, percent grass cover and percent erosion. However, the equation with the best level of significance (variables of percent herbaceous and grass cover) was used for the model application. Although models were generated for Bw thickness and depth to the C horizon, these models could not be applied as the grid points were only dug to 25 cm.

The measured O and A horizon thickness, the predicted O and A horizon thickness, and the significant variables were mapped in ArcView© (Version 3.2) (ESRI 1996) (Figures 5.1-5.23) by interpolating point data into surfaces. The surfaces are displayed using ArcGIS© ArcMap (ESRI 1999). Aspect is not mapped individually because topography is already represented in the images as elevation contour lines. The dots show sampled grid points. For each map a variable is displayed by the intensity of the color; the darker colors have larger values and the lighter colors have lower values. Similar color values across different maps cannot be assumed to have the same numeric value. Refer to the legend to determine approximate color values. Some surfaces depict color values far outside the actual variable range (i.e., very large or very small numbers); this is an artifact of the interpolation method used. The purpose of these maps is to show changes in the mapped factors across the landscape and the relationships between the variables, both measured and predicted.

To determine the accuracy of the models and the relationships the models propose, the equations were applied to the grid point data to predict O and A horizon thickness (Figures 5.1-5.23). The predicted maps compare the relative values derived from the models to the measured values. It is apparent that some predicted horizon thicknesses relate to the measured thicknesses. Also, the environmental factors that derive horizon thickness in the models can be compared to the measured and predicted horizon thickness. For example, plot Camas shows thicker O horizons (measured) where percent grass and tree cover are more dense and thinner O horizons with a greater percent of erosion. The regression equation relationships with A horizon thickness, percent erosion, and percent grass and herbaceous cover also seems reasonable in Plot Camas. However not all plots show these relationships as distinctly. In some plots only one or two factors visually relate to horizon thickness (such as Crow 1, A horizon thickness and herbaceous cover, Crow 6, O horizon thickness and percent tree and grass cover, and Slawson, A horizon thickness and percent erosion). Another thing to note is that many of the plots have south, southwest, or west aspects, which cause a greater reduction in O horizon thickness (according to the regression model, equation 4.1).

Many of the surfaces do not correlate well. The model for O horizon appears to provide a more accurate measure than the model for A horizon thickness. This is also shown in Figure 5.24, that displays O and A horizon measured thickness over the predicted thickness. The O horizon chart shows a trend line with a greater slope, indicating a better relationship. As explained in the previous chapter, O horizons may be easier to model due to the shorter time it takes for formation.

The applications of the models for O and A horizon thickness are a good start in determining variables that impact the soil and to what extent. For example, it is likely that canopy cover largely contributes to O horizon thickness. However, some plots show more accuracy in predicting horizon thickness than others. It is obvious that not all factors affecting horizon thickness are included in the models. Additionally, different variables and interactions of variables may be impacting the soil differently on different plots.

There are a number of reasons why the models do not accurately predict the horizon thicknesses. The possibilities suggested by Phillips et al. (1996) in Chapter 2, are that not enough data were collected, the data are not accurate enough to make significant determinations, or deterministic uncertainty is complicating the site. Deterministic uncertainty is possible on these sites based on the small amount of variability explained by the models. Also, the fact that many disturbances on the sites, such as fire, could have lead to soil inconsistencies, which increased into large variability over time (Phillips et al.

1996). Additionally, Barrett (2001) discussed "regressive pedogenesis" on microsites that have been disturbed. This process is very likely in the area of the Wenatchee Mountains. Therefore, all causes of soil variability may not be evident on the site. However, it is too early to deem deterministic uncertainty as the culprit for the remaining unexplained variability in this area. More data should be collected and explanations exhausted before that distinction is made.

The landscape of this study area is dynamic. Due to the steep slopes, erosion is very common. Therefore over time the soil can be thought of as "flowing." This can be observed in the data and GIS maps as thicker soil horizons and soil depth in valleys and depressions. Even though topography was not a significant factor, erosional and depositional events seem to occur at these sites, similar to the research by Marron and Popenoe (1986), Miller et al. (1988), Moore et al. (1993), Stolt et al. (1993), and Webb and Burgham (1997). Therefore it is surprising that topography was not more influential than vegetation in modeling soil horizon thickness. However, erosion and deposition, or soil "flow," may be more complicated, and may not be dictated solely by topography.

Soil flow is just one example of disturbance history that is not well documented on the study site. Various degrees of disturbance have occurred in this area for centuries, including logging, grazing, wildfire, and ground burning. Many of these events are not recorded and have long lasting and complex effects on the soil. For example, past wildfire occurrence could affect vegetation patches, erosion and soil properties. In order to gain a better understanding and model of the soil, more research and data may need to be collected on disturbance in the study area.

Another potential factor that is not well understood on the study site is ash deposits. The east slopes of the Washington Cascades receive ash fallout from many major volcanoes. No literature was found that documented compositions and depth of deposits in this area. The ashfall that is known to affect the study site are from the Mount Mazama and Mount St. Helens (Mullineaux 1974, Beget 1981, Fisher and Schmincke 1984). Glacier peak eruptions, from 11,250-12,500 years B.P., did not deposit ash on this area (Beget 1981). This study measured ash content as a categorical measure by horizon. The results from these data were not significant in determining horizon thickness for any horizon. However, more specific data such as, numeric values for ash content, depth of deposits, and ash type, may increase the significance of ash in modeling horizon thickness. Furthermore, the amount of erosion that occurs on the study site will complicate ash deposit quantification because the ash will move across the landscape depending on erosion. Ash deposits may have great effect on soil depth, horizon thickness, horizon type and formation, as well as many other physical and chemical soil properties. Further information on the amount and type of ash found on the site would increase understanding of these soils.

Much research has been done on the interactions of site factors and their influence on the soil, however no research was found to indicate that interactions have been studied in the study site area. Because environmental interactions are site specific, it is unlikely that other research can explain the interactions that occur on the Wenatchee Mountains. However it is certain that interactions are present on the site. The specifics of the interactions are yet to be determined. Possible interactions include topography (aspect, slope position, and slope percent), climate (rainfall, and evaporation), vegetation (photosynthesis, productivity, percent cover, and type), disturbance (erosion and deposition) and soil horizon thickness.

On topographically variable landscape that exhibits vegetation patches such as this site, it is difficult to determine which environmental factors could potentially be significant in predicting soil properties. By selecting a site with relatively static climate, ecosystem type, parent material, and age it was expected that finding and predicting soil horizon variability could be accomplished with topographic and vegetation density data. Though this research did provide significant models, the full breadth of relationships between the soil and the environment is yet to be understood at the study site. Therefore, the second objective, to determine if predictable soil patterns or models can be derived, was met and soil predictions are determined to be unreliable.

IMPLICATIONS

This study is part of the national Fire and Fire Surrogate research. The data and analysis discussed here are the pre-treatment stage of the study. On highly variable experimental plots, it is crucial to evaluate and quantify the range in variability prior to treatment application. Without this evaluation and baseline data, site variability could mask treatment effects.

In this case, in order to determine treatment effects, post-treatment data will have to be collected at the same points on the landscape as the pre-treatment data. The range in variability of all the factors measured in this research is quite extensive on a relatively small scale (80 m). Because of this variability, treatment effects may not be able to be determined if the data are averaged over the entire area, or even by plot. It is difficult to even determine current soil conditions over a single plot. Therefore the results of the treatments should evaluated point by point.

This study also has implications for future management practices. As more is learned about the soil on dry-site forests and which environmental factors impact the soil, the more managers can do to reduce erosion and increase soil health and productivity. For example, given that grass cover and canopy cover increase O horizon thickness and south aspects result in reduced O horizon thickness, a manager may limit the disturbance impacts on south slopes that would reduce grass and tree cover, such as logging or hiking trails. Through this and similar research, dry site forest managers can apply land use practices with more knowledge about factors that increase and decrease soil thickness.

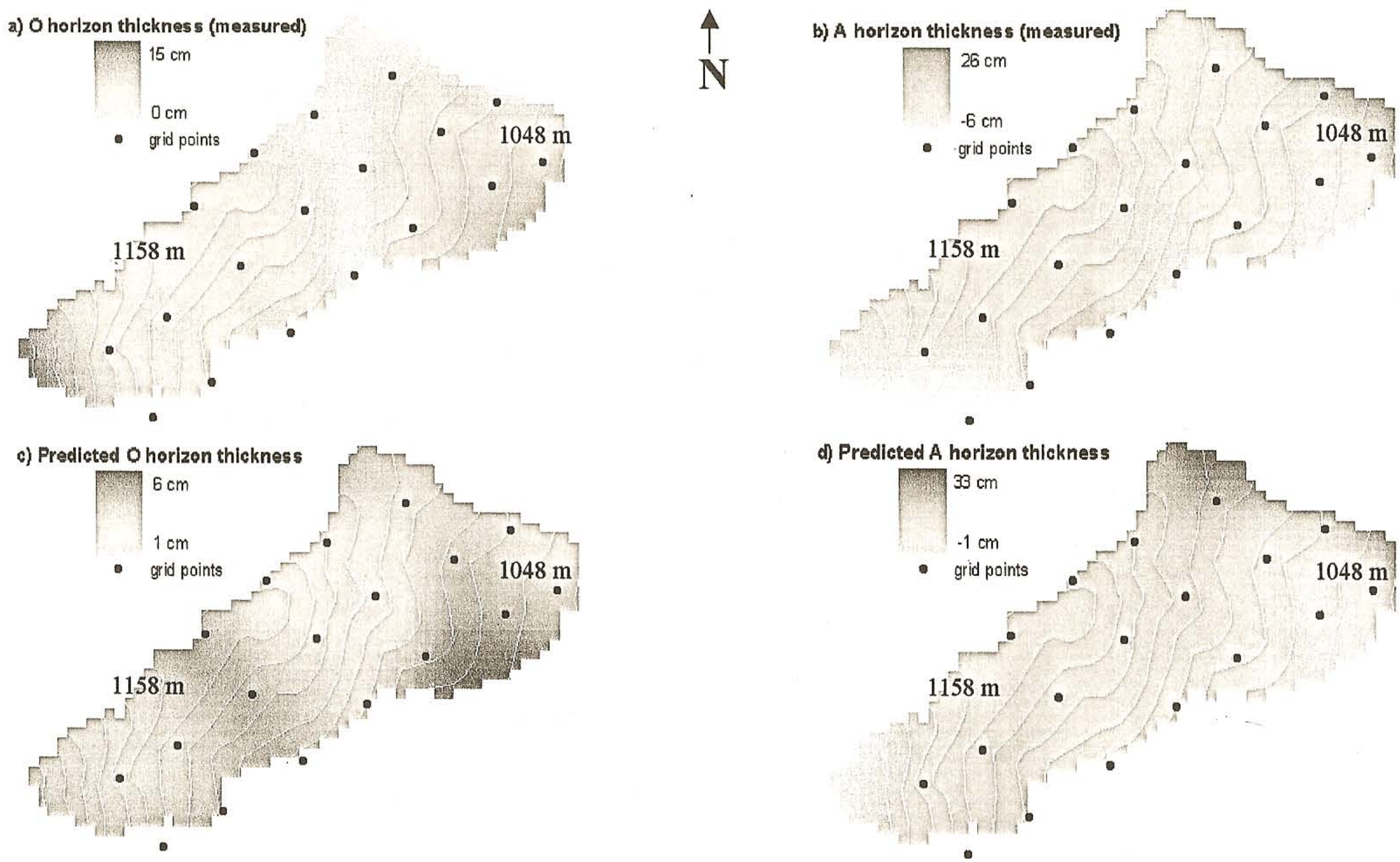


Figure 5.1. Interpolated surfaces of Plot Camas with, a) O horizon thickness (measured), b) A horizon thickness (measured), c) predicted O horizon thickness, d) predicted A horizon thickness. Negative values are the result of a spline interpolation between or beyond data points.

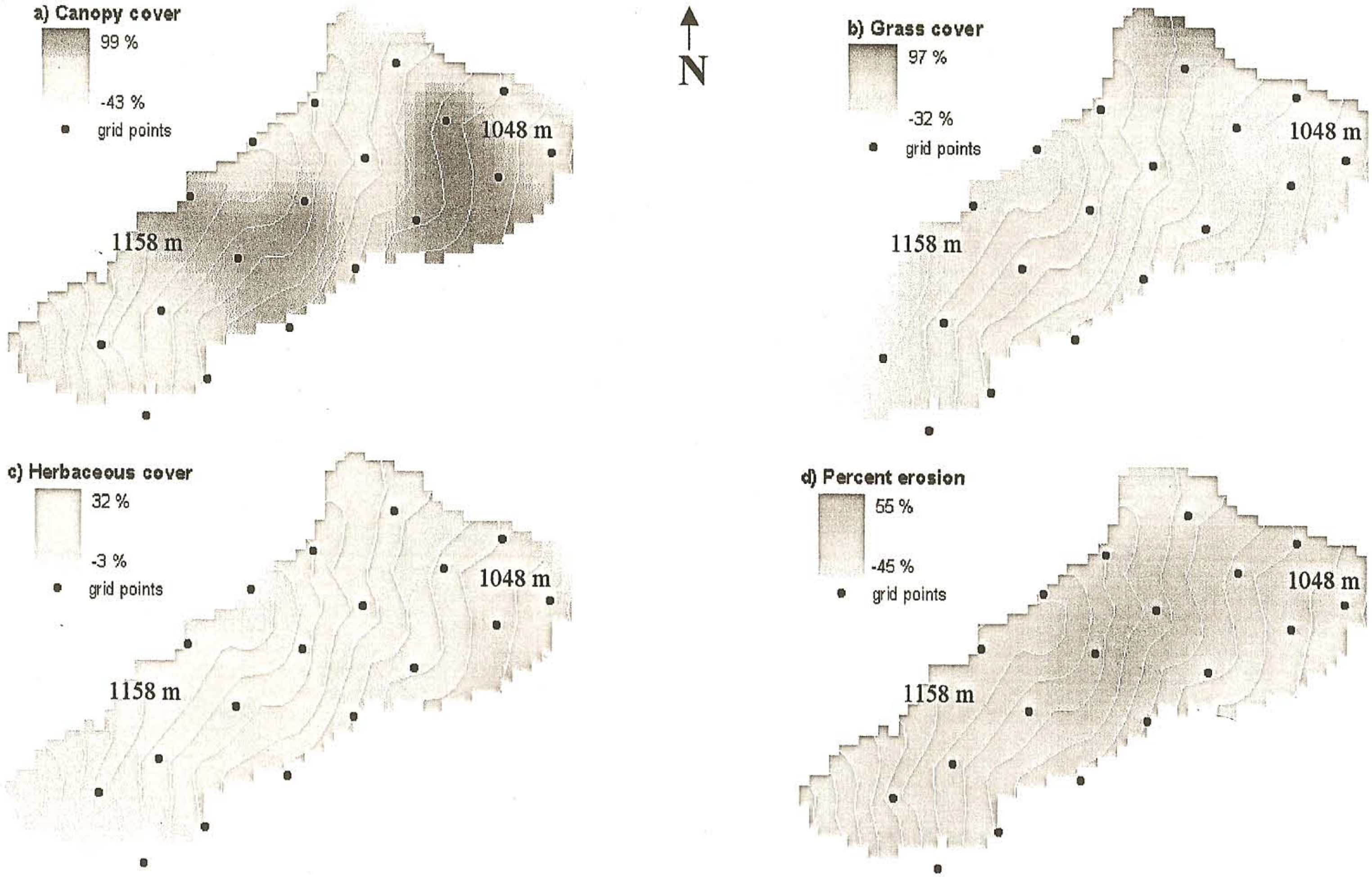


Figure 5.2. Interpolated surfaces of Plot Camas with, a) Canopy cover, b) Grass cover, c) Herbaceous cover, and d) Erosion. Negative are the result of a spline interpolation between or beyond data points.

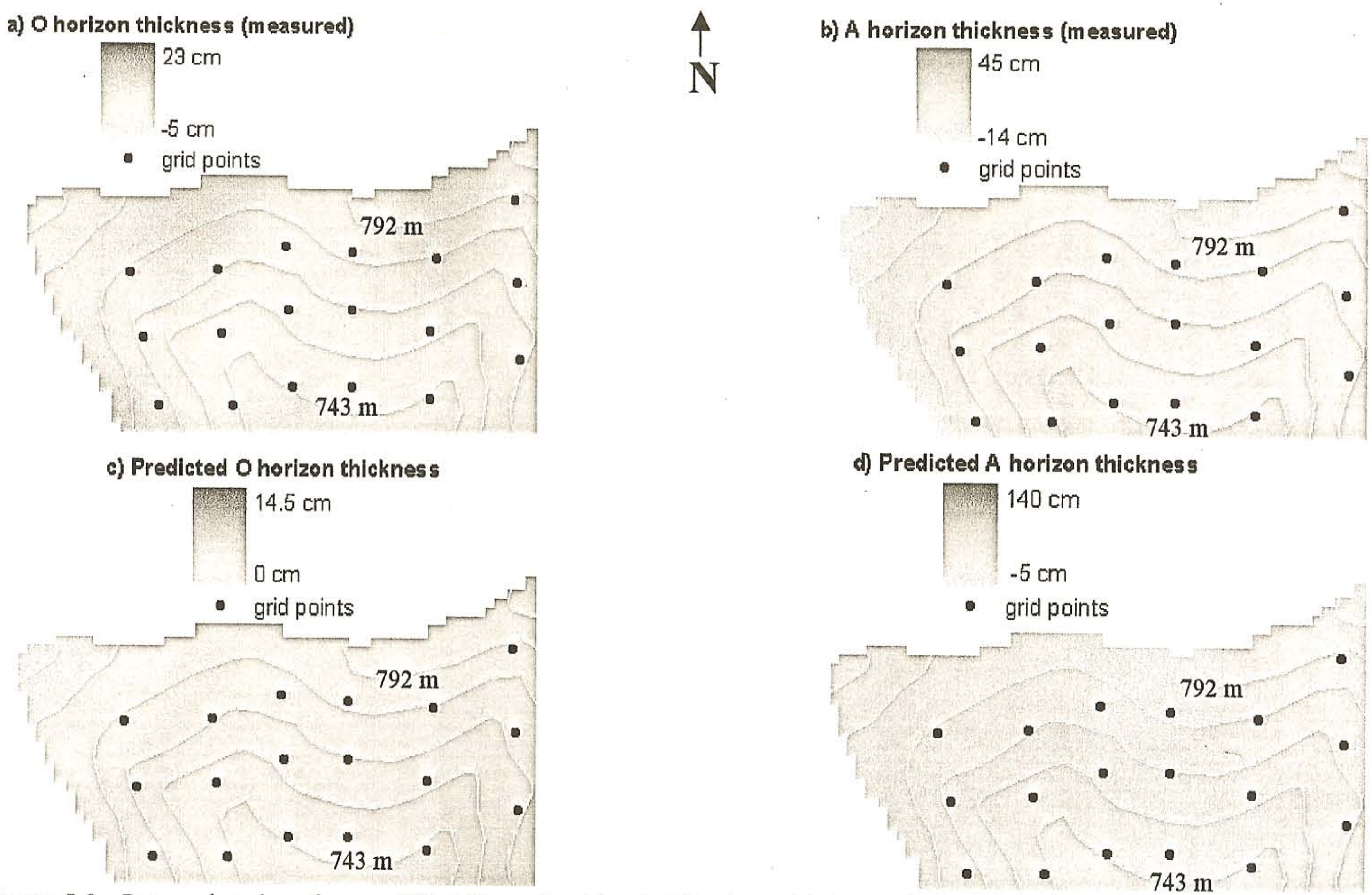


Figure 5.3. Interpolated surfaces of Plot Crow 1 with, a) O horizon thickness (measured), b) A horizon thickness (measured), c) predicted O horizon thickness, d) predicted A horizon thickness. Negative values are the result of a spline interpolation between or beyond data points.

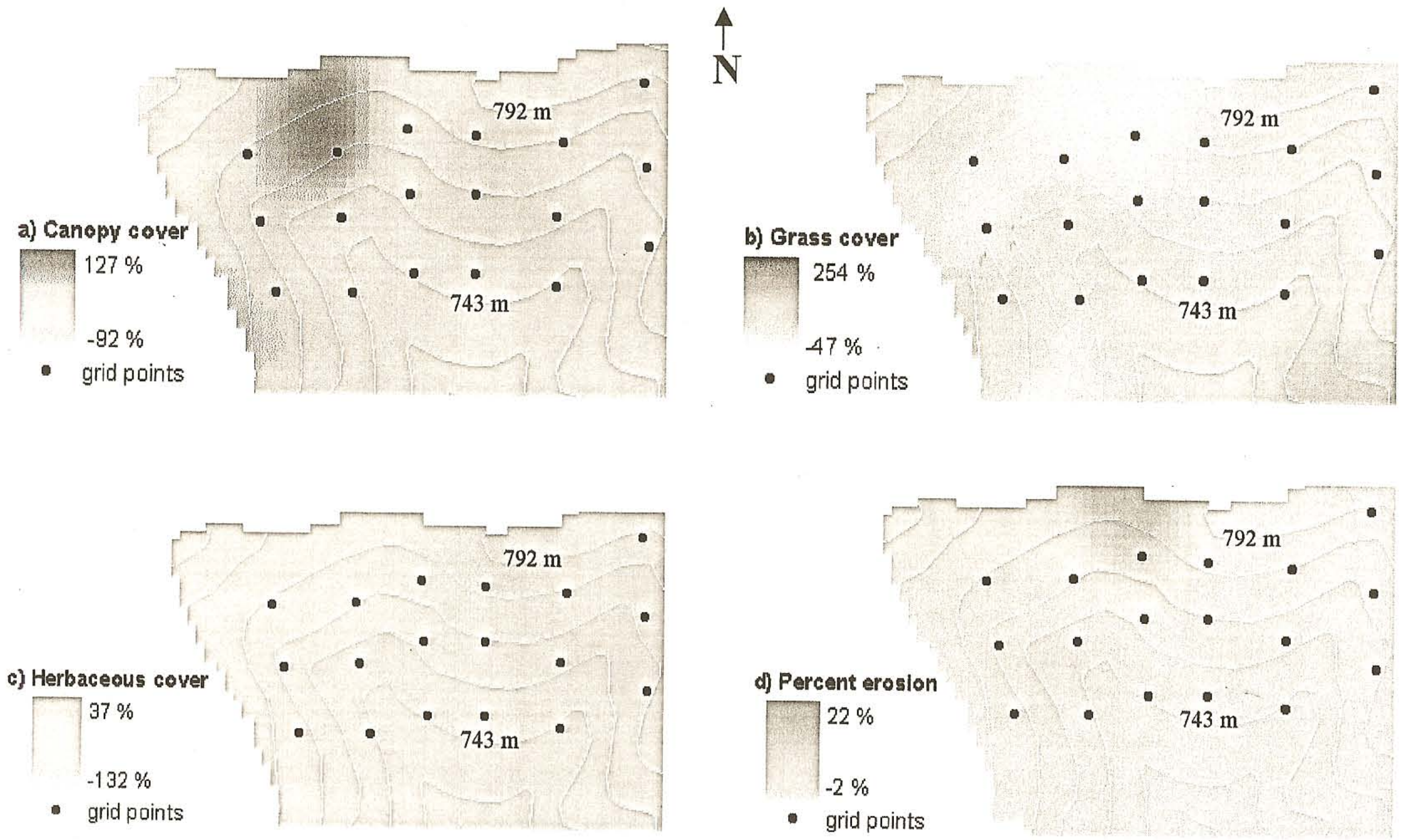


Figure 5.4. Interpolated surfaces of Plot Crow 1 with, a) Canopy cover, b) Grass cover, c) Herbaceous cover, and d) Erosion. Negative and extreme positive values are the result of a spline interpolation between or beyond data points.

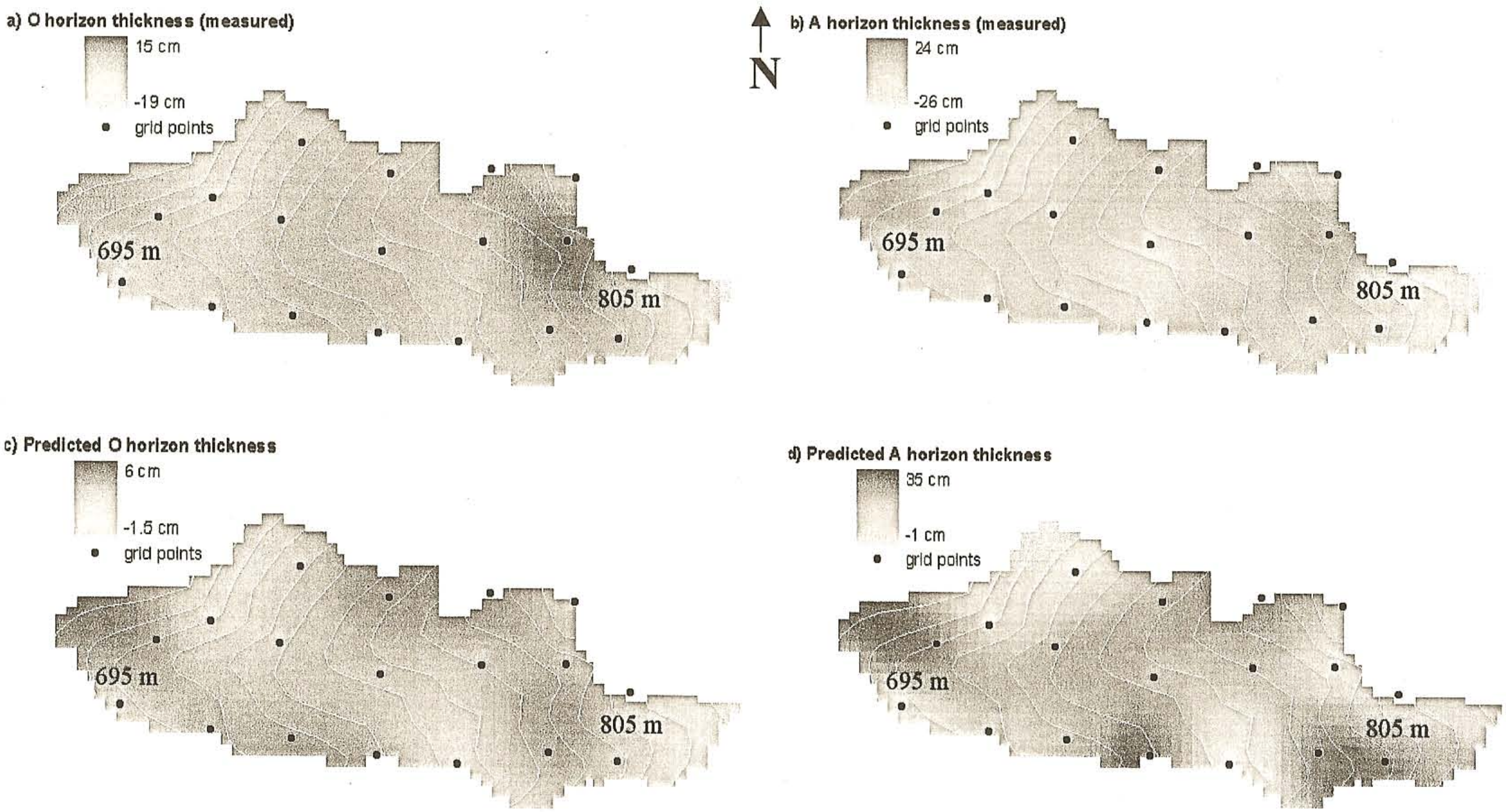


Figure 5.5. Interpolated surfaces of Plot Crow 3 with, a) O horizon thickness (measured), b) A horizon thickness (measured), c) predicted O horizon thickness, d) predicted A horizon thickness. Negative values are the result of a spline interpolation between or beyond data points.

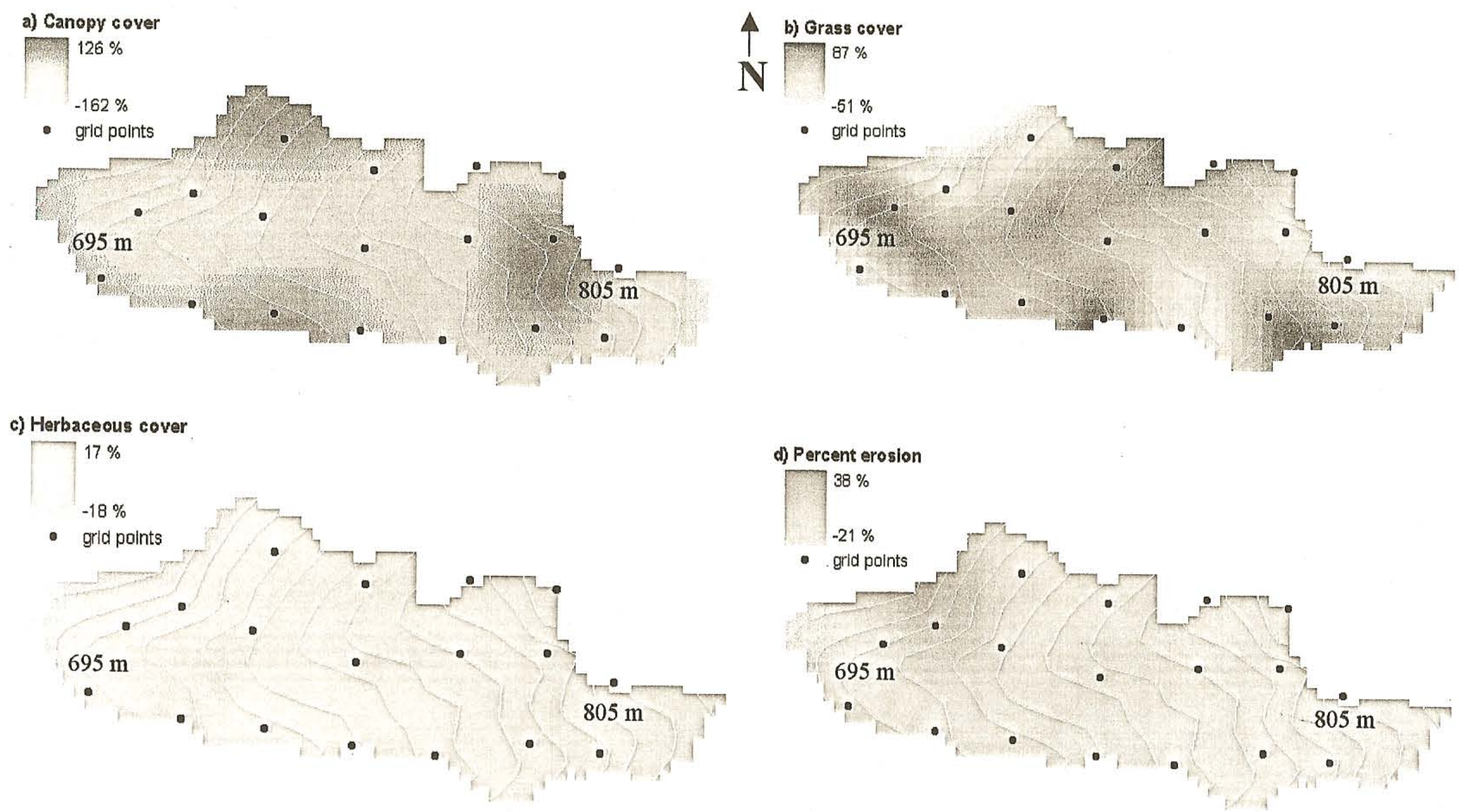


Figure 5.6. Interpolated surfaces of Plot Crow 3 with, a) Canopy cover, b) Grass cover, c) Herbaceous cover, and d) Erosion. Negative and extreme positive values are the result of a spline interpolation between or beyond data points.

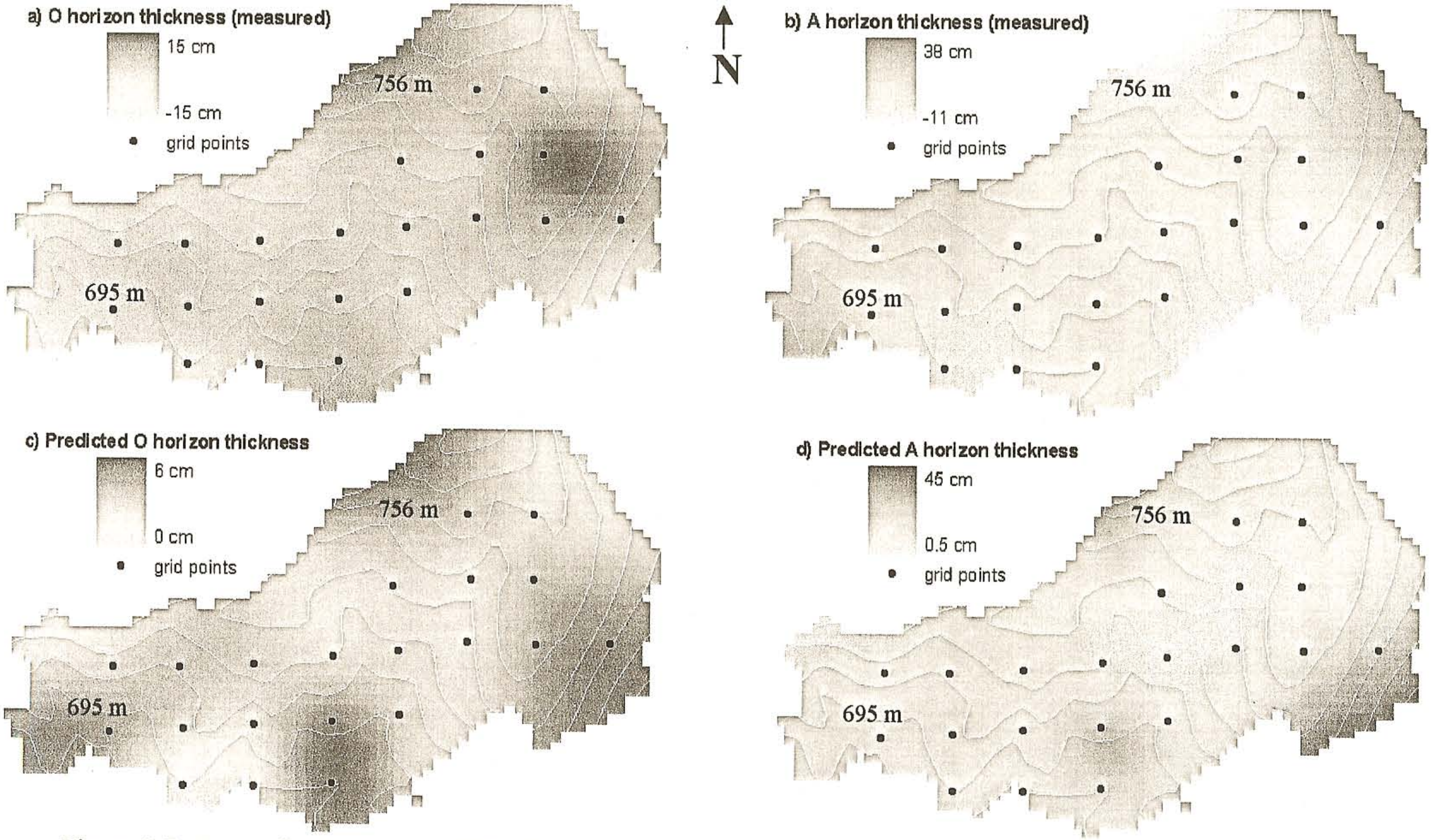


Figure 5.7. Interpolated surfaces of Plot Crow 6 with, a) O horizon thickness (measured), b) A horizon thickness (measured), c) predicted O horizon thickness, d) predicted A horizon thickness. Negative values are the result of a spline interpolation between or beyond data points.

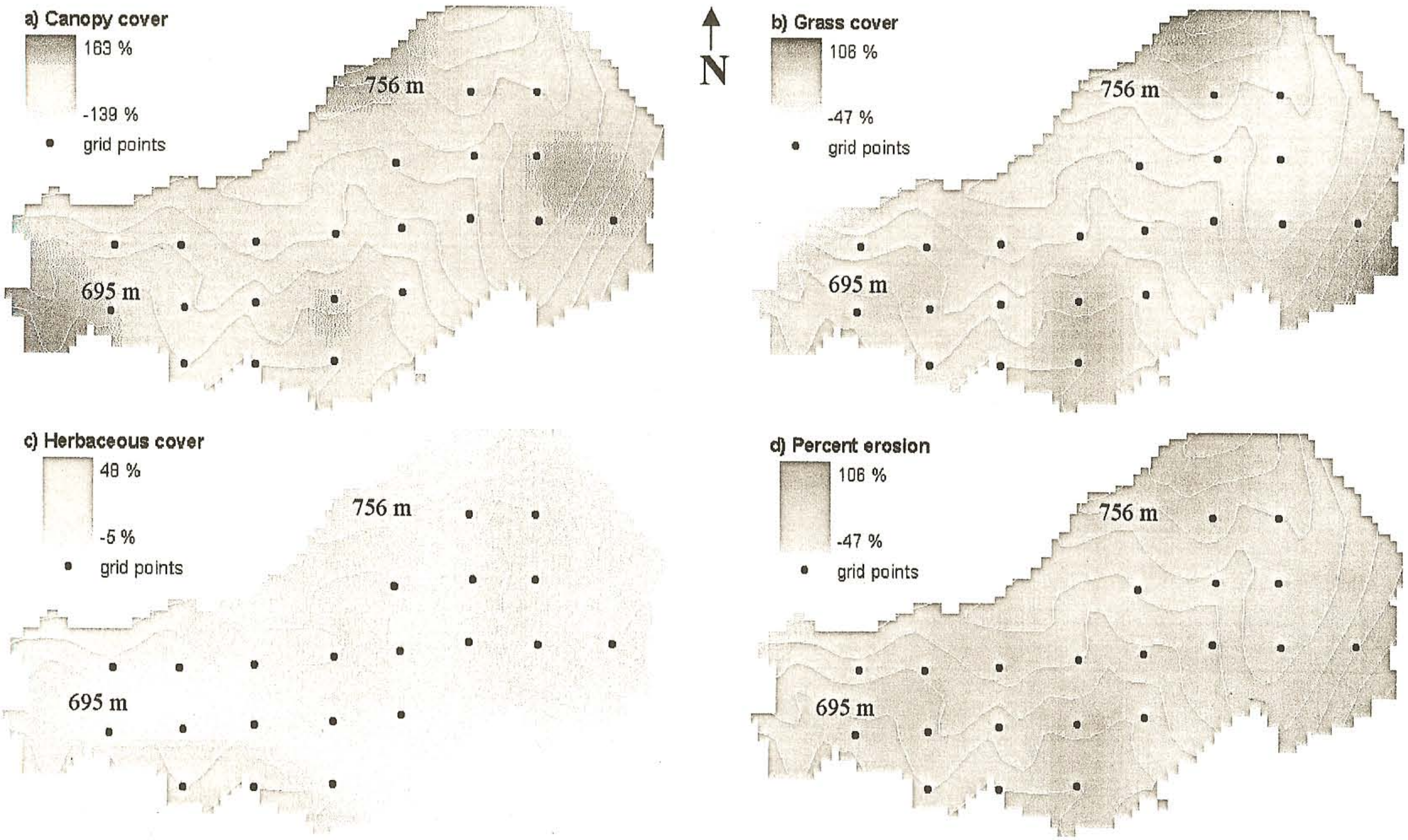


Figure 5.8. Interpolated surfaces of Plot Crow 6 with, a) Canopy cover, b) Grass cover, c) Herbaceous cover, and d) Erosion. Negative and extreme positive values are the result of a spline interpolation between or beyond data points.

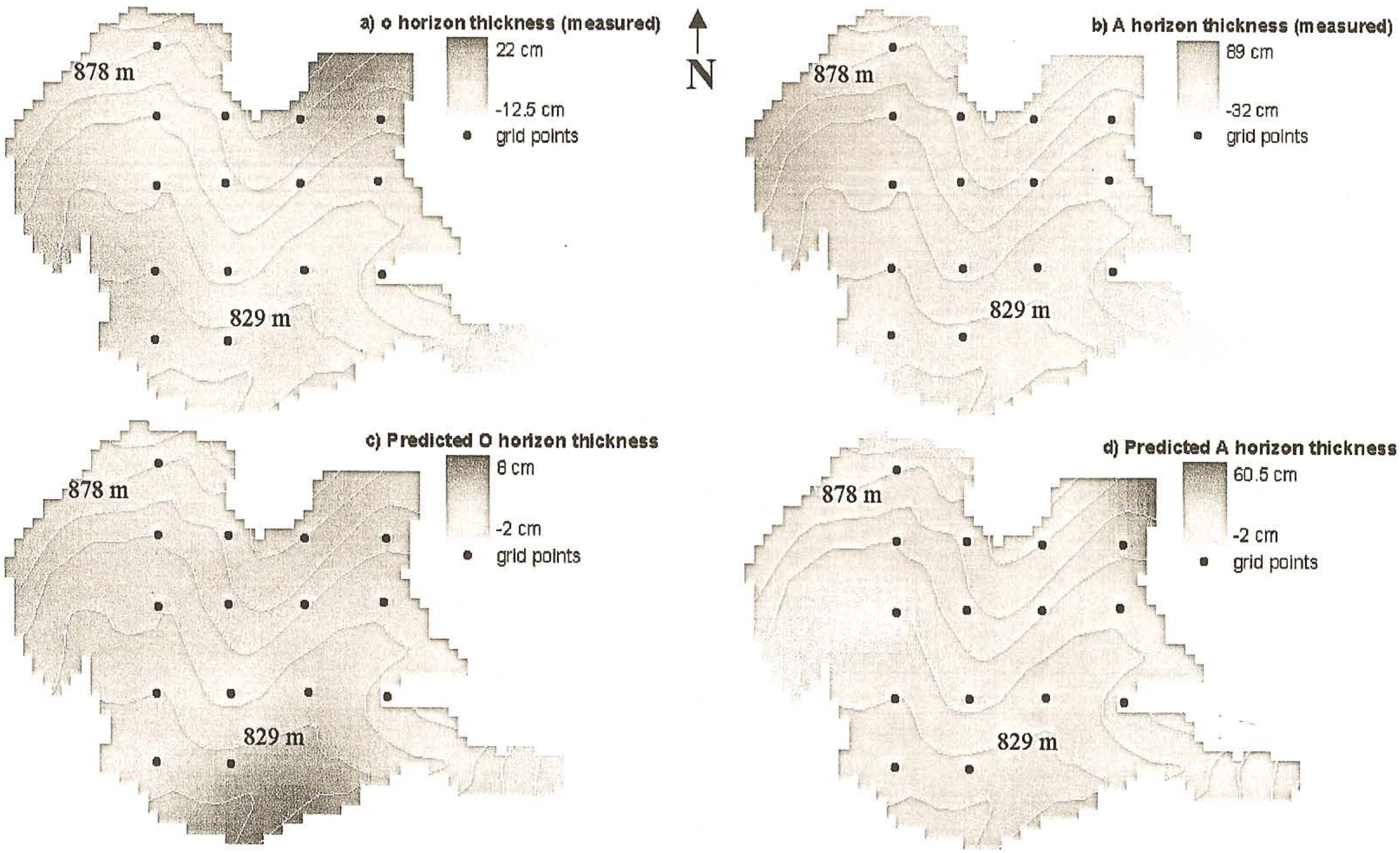


Figure 5.9. Interpolated surfaces of Plot Pendleton with, a) O horizon thickness (measured), b) A horizon thickness (measured), c) predicted O horizon thickness, d) predicted A horizon thickness. Negative values are the result of a spline interpolation between or beyond data points.

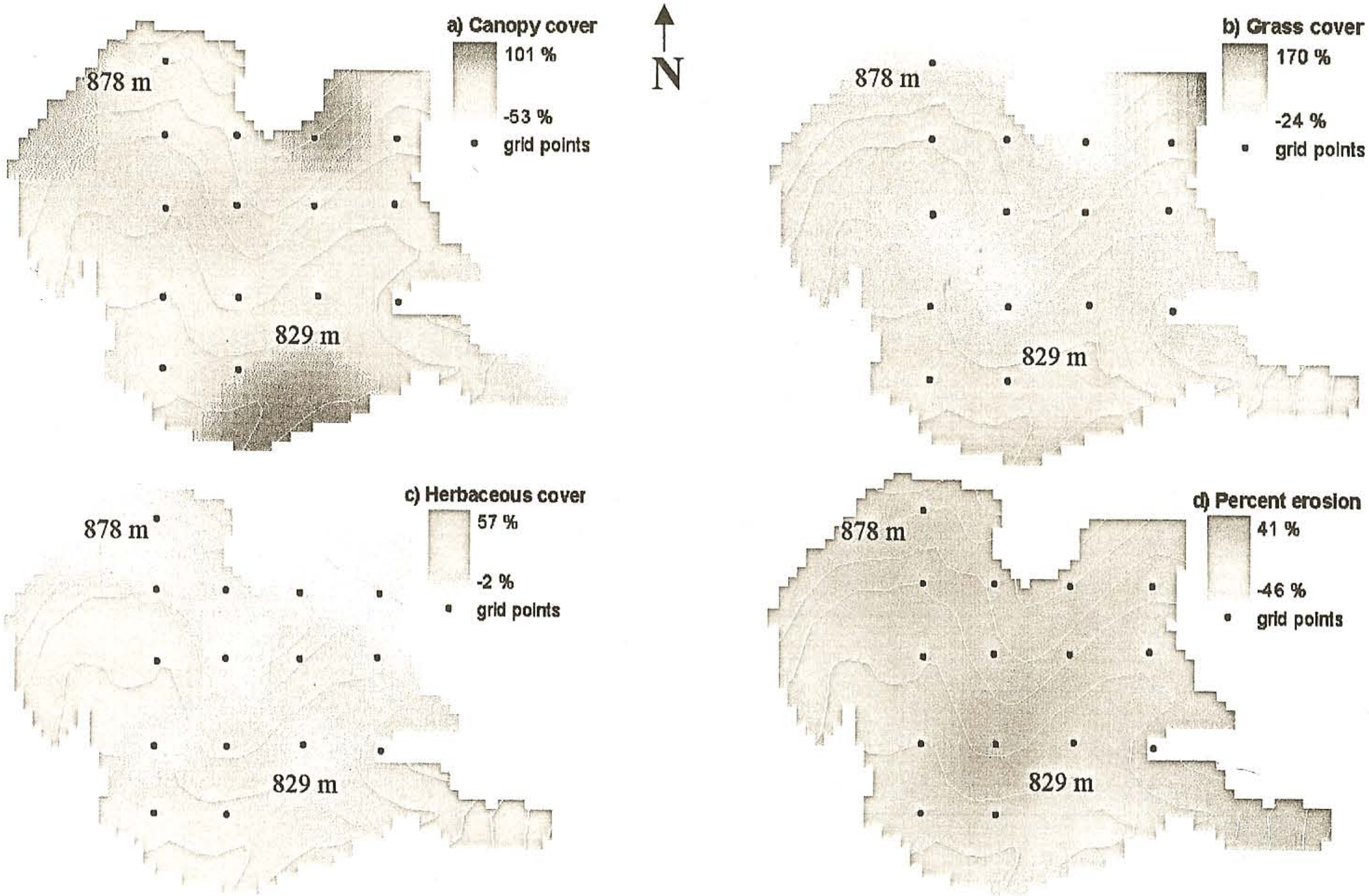


Figure 5.10. Interpolated surfaces of Plot Pendleton with, a) Canopy cover, b) Grass cover, c) Herbaceous cover, and d) Erosion. Negative and extreme positive values are the result of a spline interpolation between or beyond data points.

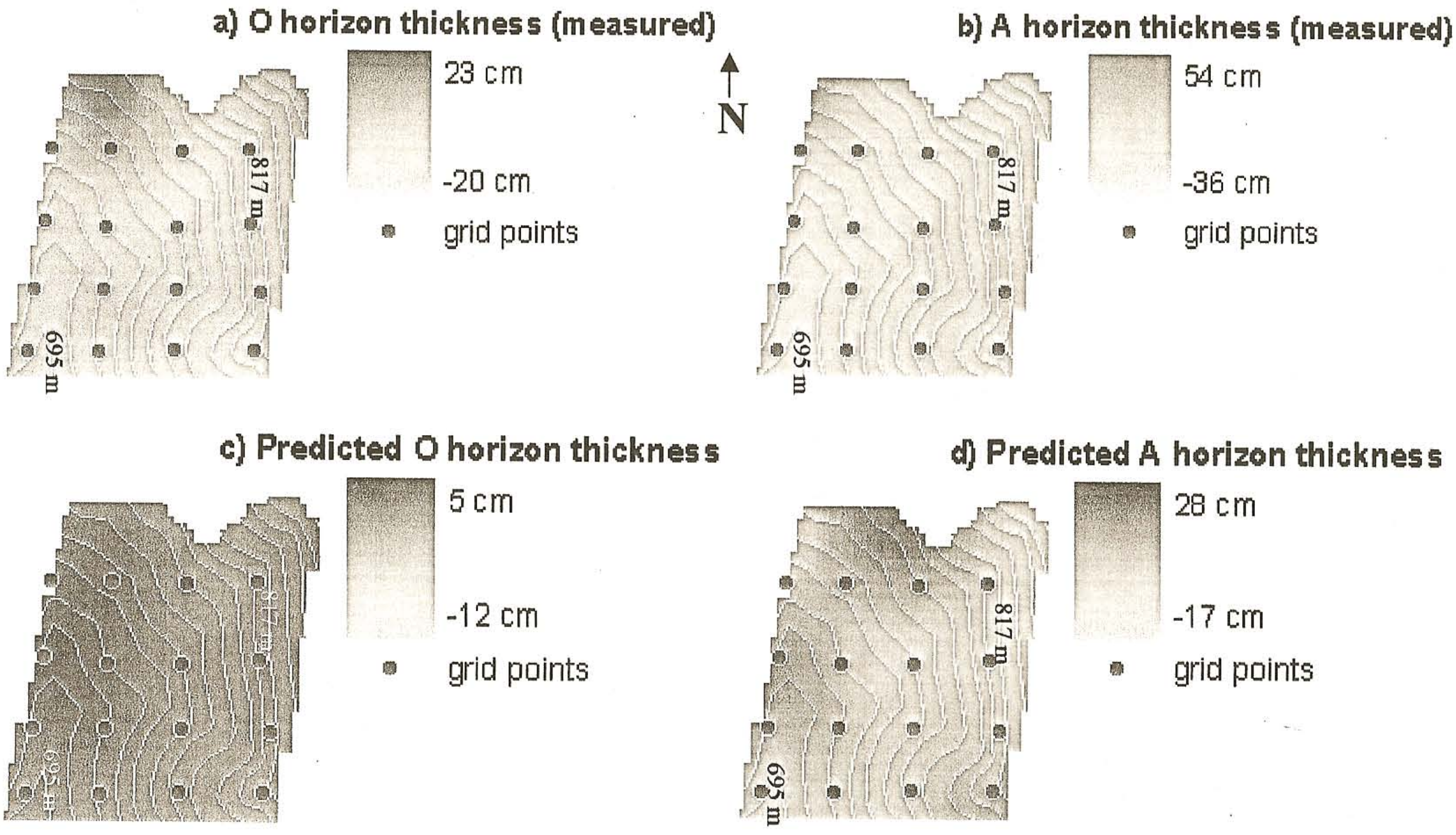


Figure 5.11. Interpolated surfaces of Plot Poison with, a) O horizon thickness (measured), b) A horizon thickness (measured), c) predicted O horizon thickness, d) predicted A horizon thickness. Negative values are the result of a spline interpolation between or beyond data points.

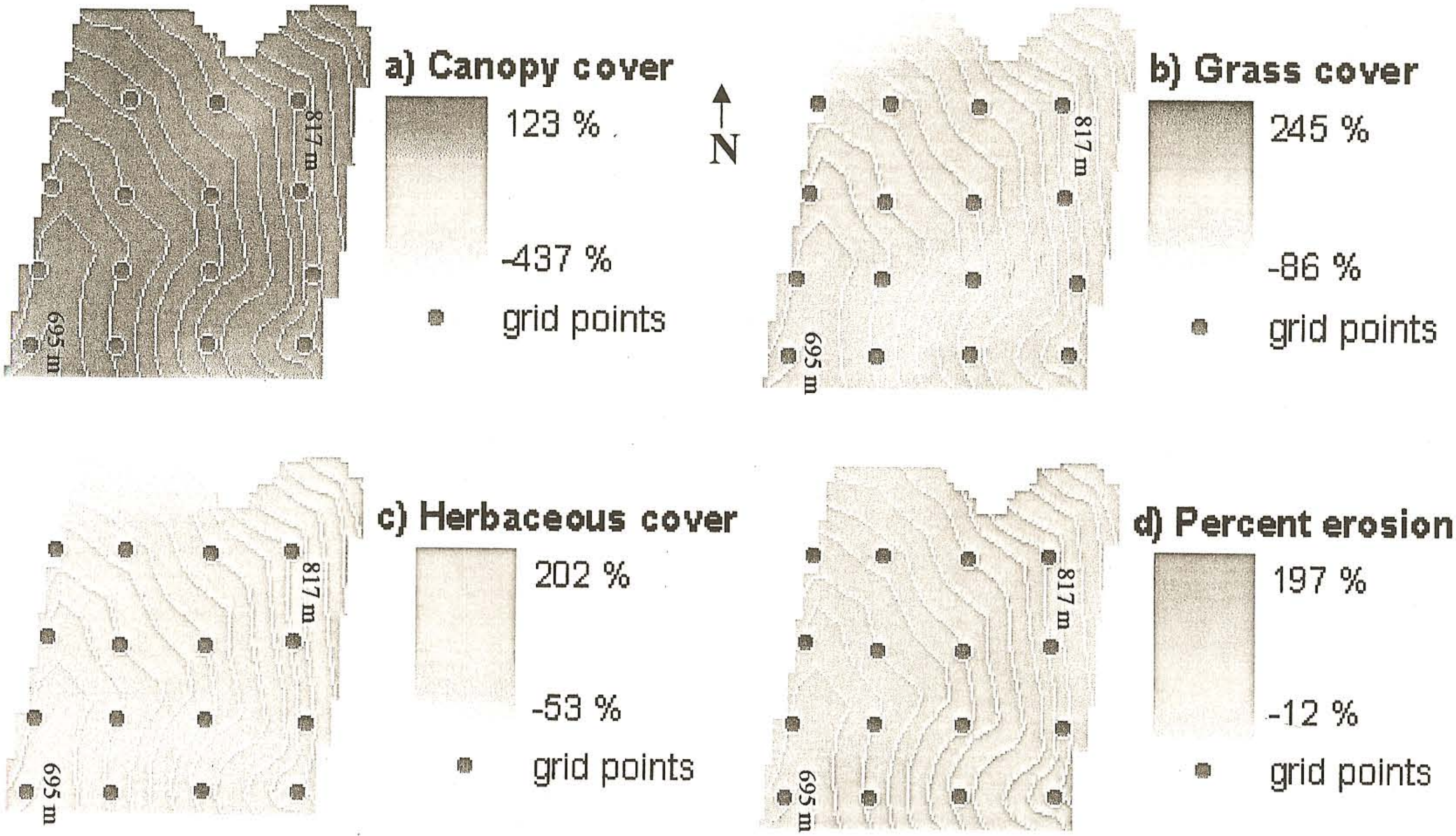


Figure 5.12. Interpolated surfaces of Plot Poison with, a) Canopy cover, b) Grass cover, c) Herbaceous cover, and d) Erosion. Negative and extreme positive values are the result of a spline interpolation between or beyond data points.

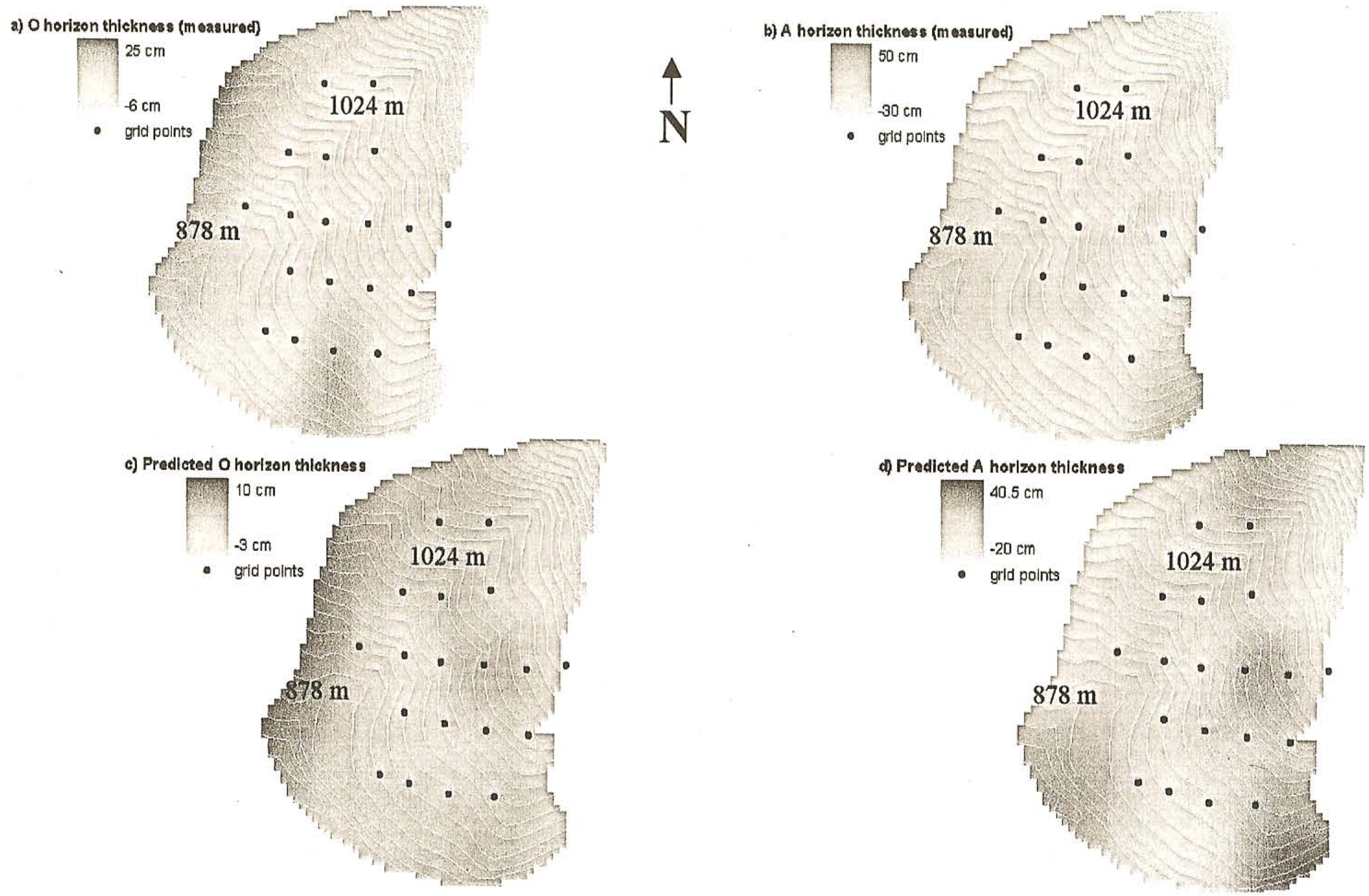


Figure 5.13. Interpolated surfaces of Plot Ruby with, a) O horizon thickness (measured), b) A horizon thickness (measured), c) predicted O horizon thickness, d) predicted A horizon thickness. Negative values are the result of a spline interpolation between or beyond data points.

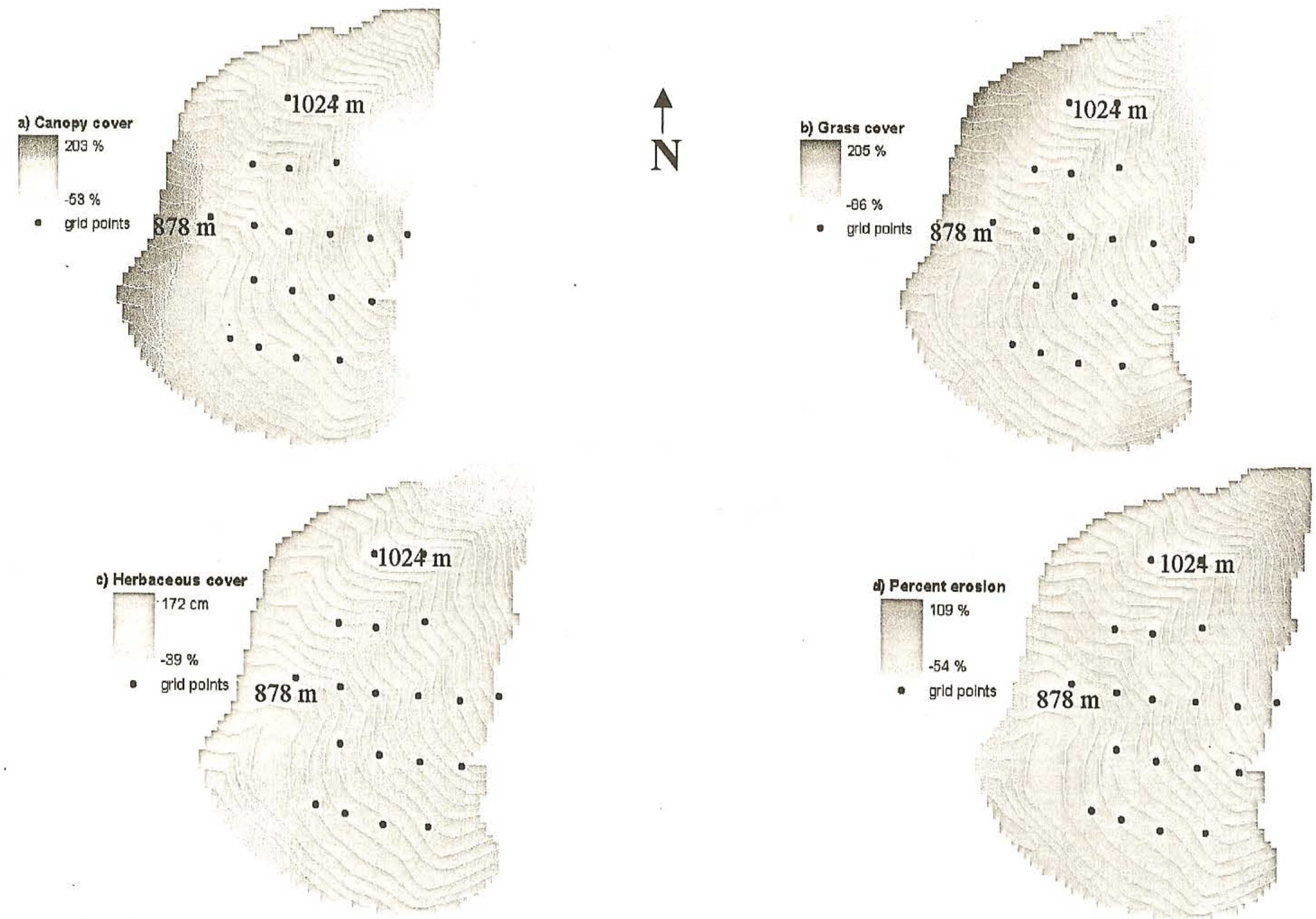


Figure 5.14. Interpolated surfaces of Plot Ruby with, a) Canopy cover, b) Grass cover, c) Herbaceous cover, and d) Erosion. Negative and extreme positive values are the result of a spline interpolation between or beyond data points.

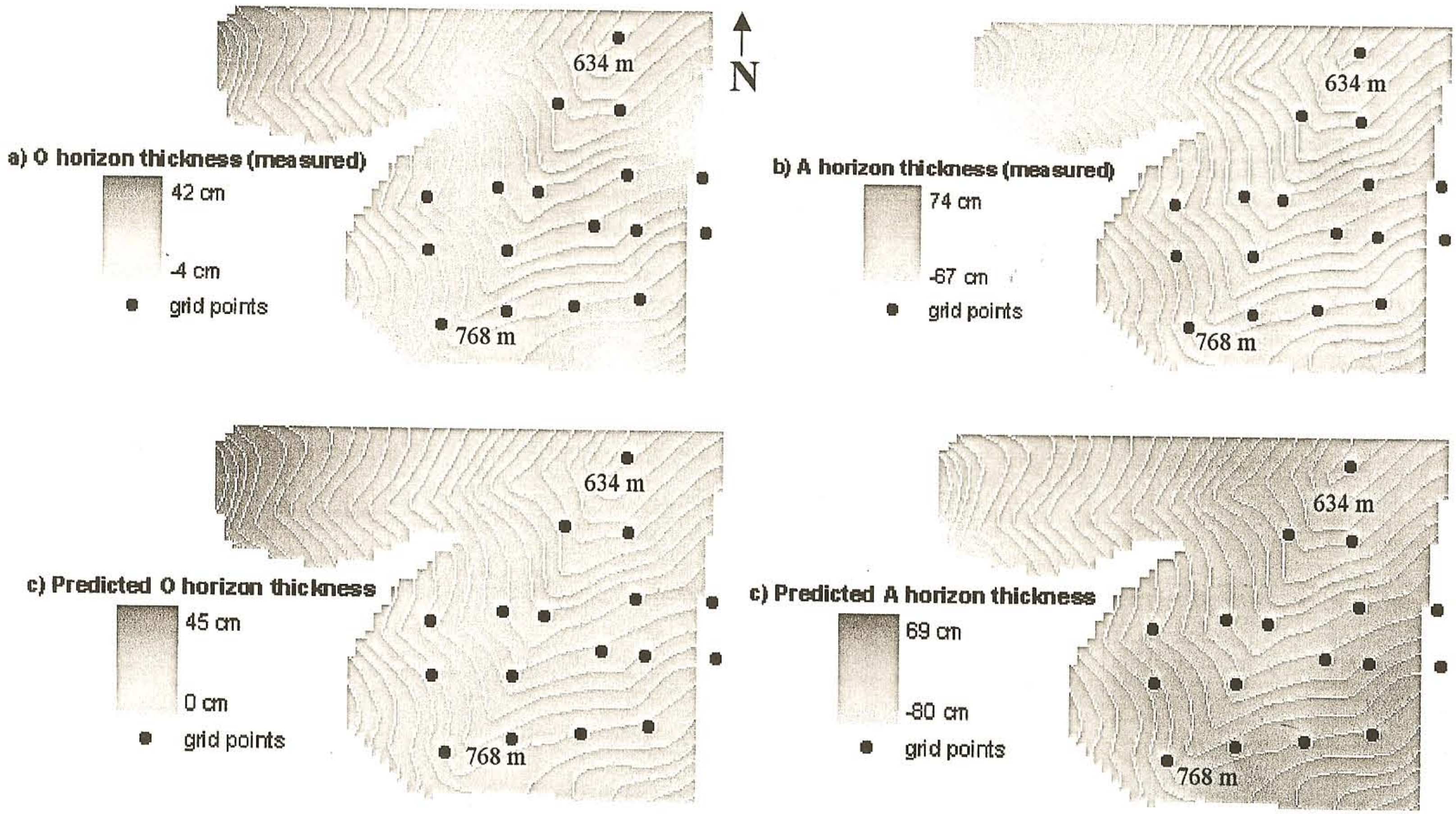


Figure 5.15. Interpolated surfaces of Plot Sand 2 with, a) O horizon thickness (measured), b) A horizon thickness (measured), c) predicted O horizon thickness, d) predicted A horizon thickness. Negative and extreme positive values are the result of a spline interpolation between or beyond data points.

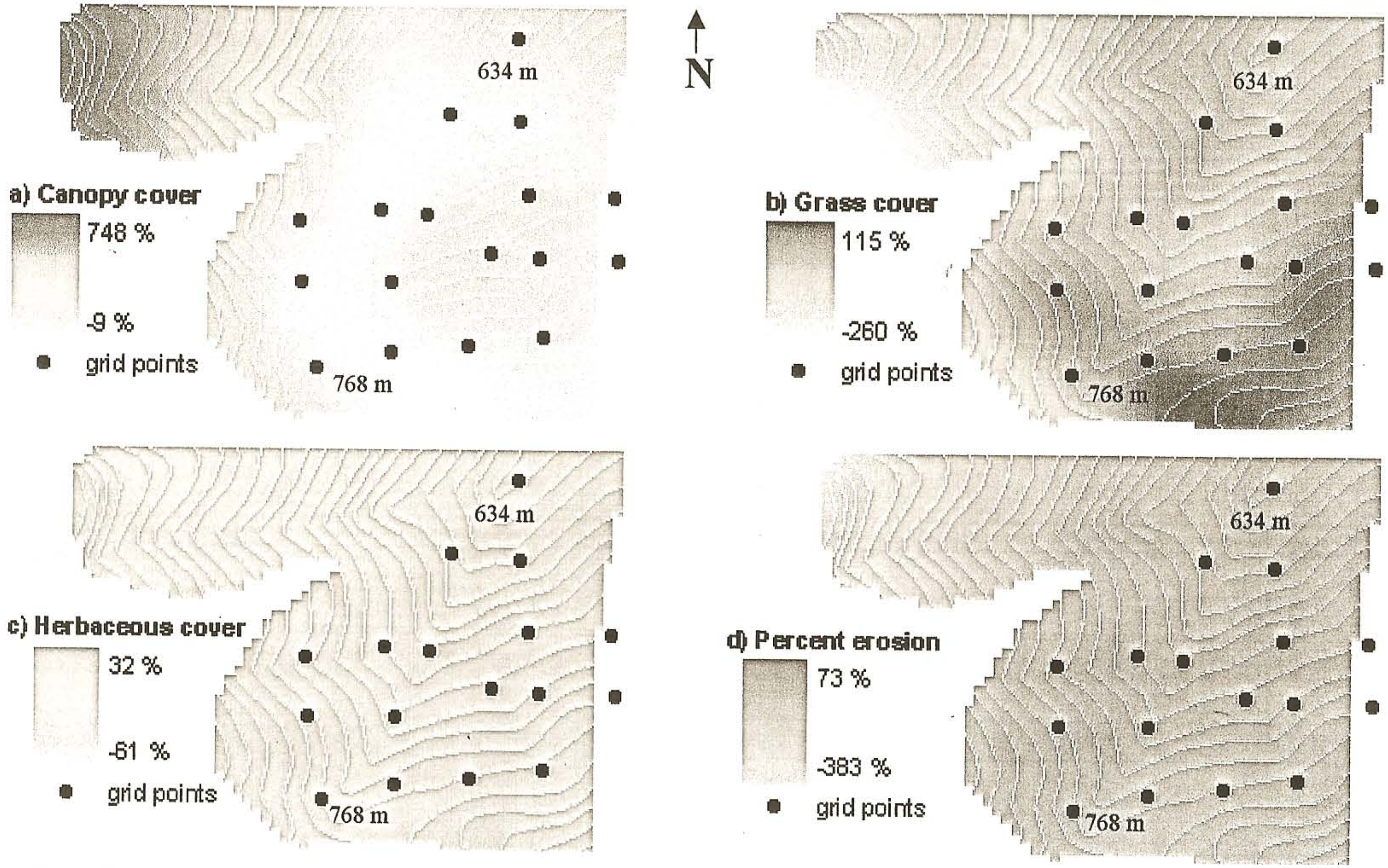


Figure 5.16. Interpolated surfaces of Plot Sand 2 with, a) Canopy cover, b) Grass cover, c) Herbaceous cover, and d) Erosion. Negative and extreme positive values are the result of a spline interpolation between or beyond data points.

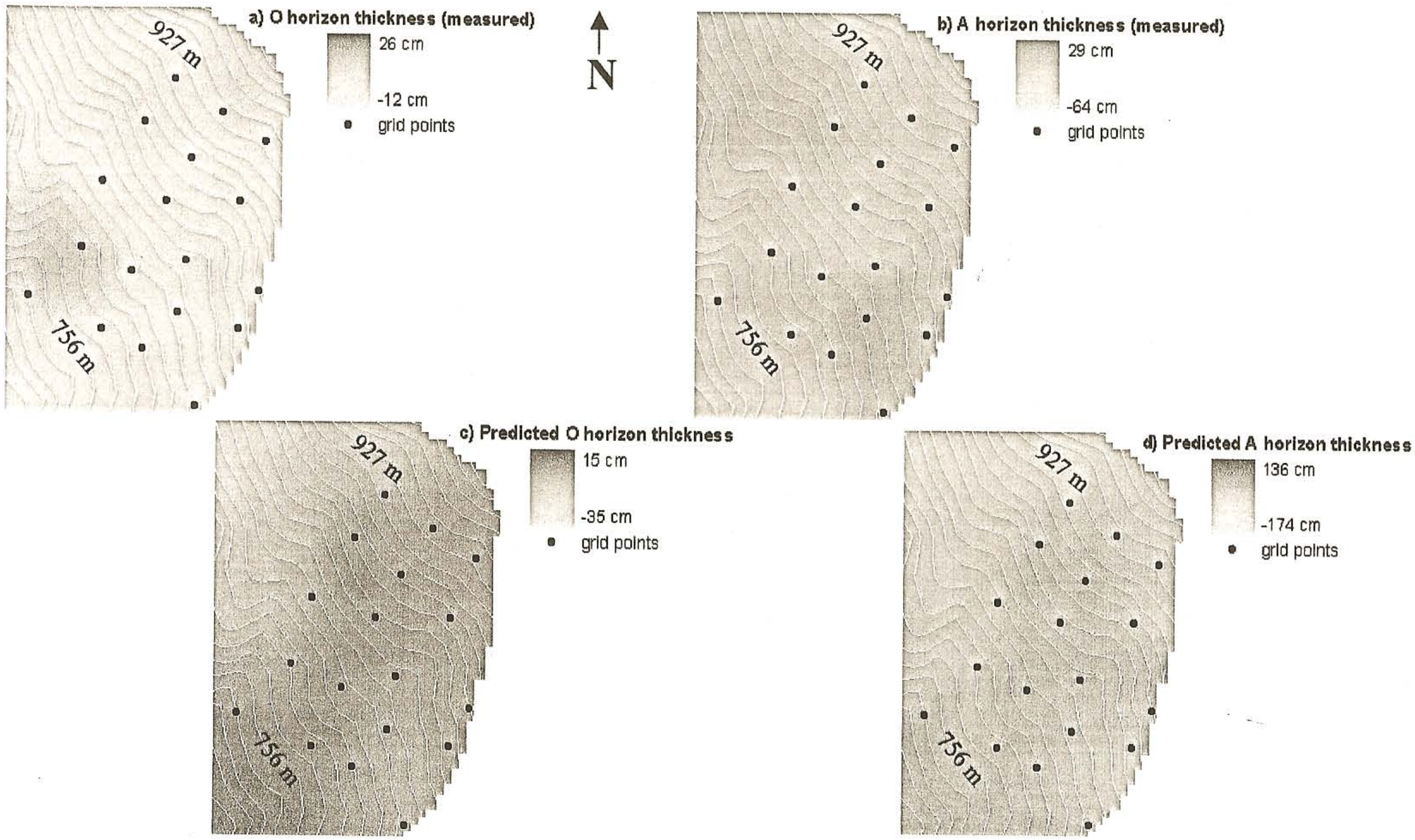


Figure 5.17. Interpolated surfaces of Plot Sand 19 with, a) O horizon thickness (measured), b) A horizon thickness (measured), c) predicted O horizon thickness, d) predicted A horizon thickness. Negative values are the result of a spline interpolation between or beyond data points.

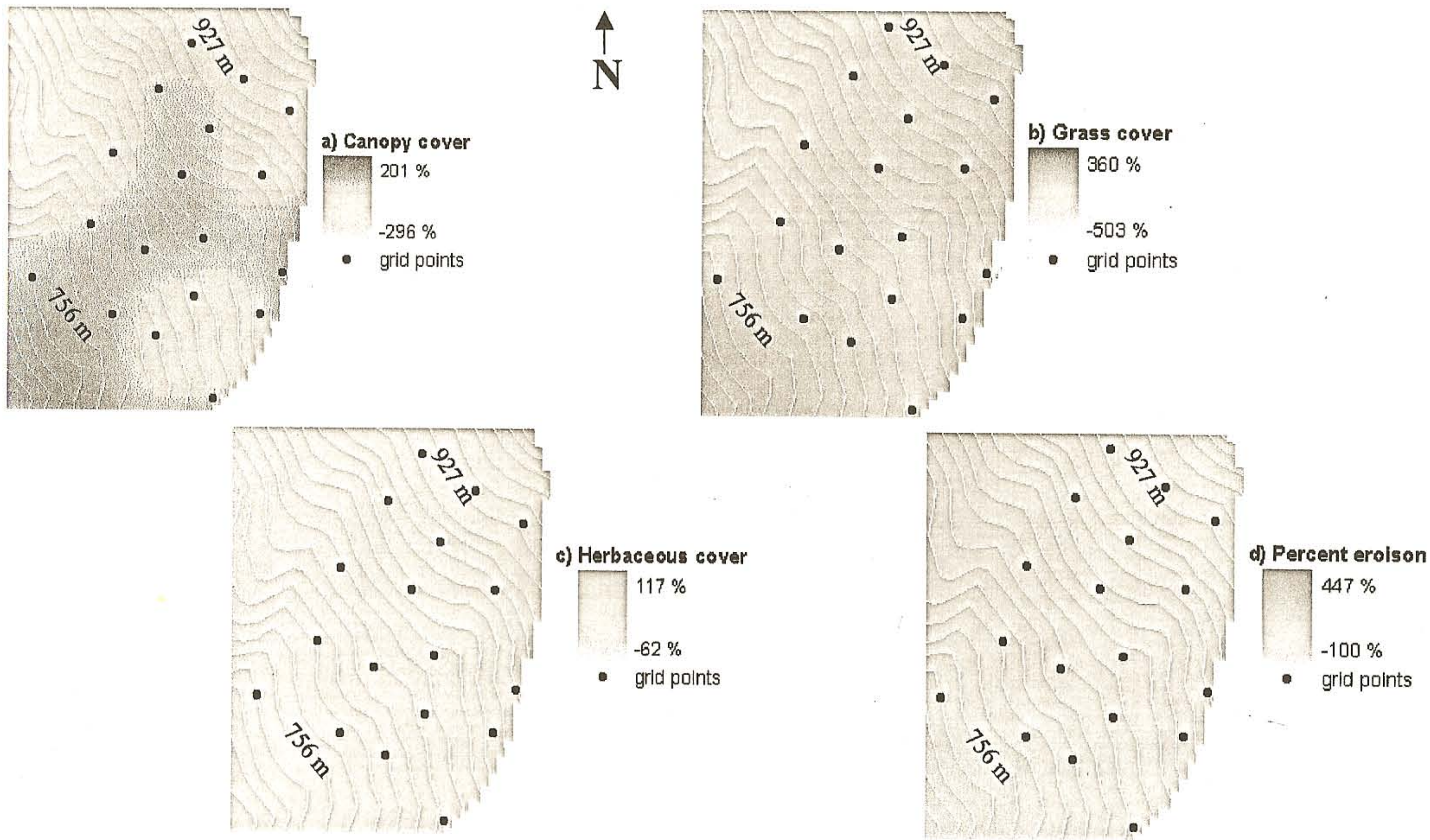


Figure 5.18. Interpolated surfaces of Plot Sand 19 with, a) Canopy cover, b) Grass cover, c) Herbaceous cover, and d) Erosion. Negative and extreme positive values are the result of a spline interpolation between or beyond data points.

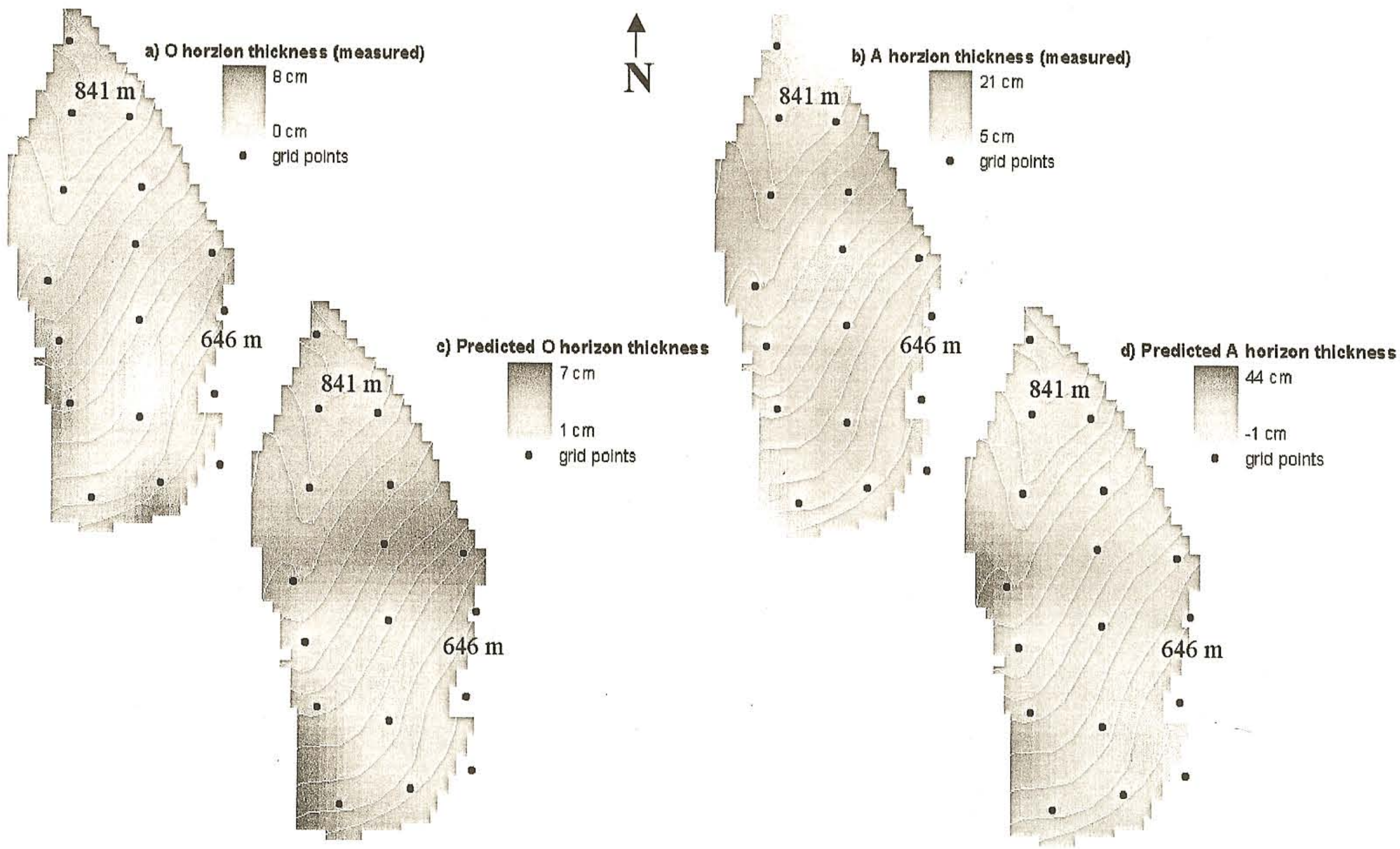


Figure 5.19. Interpolated surfaces of Plot Slawson with, a) O horizon thickness (measured), b) A horizon thickness (measured), c) predicted O horizon thickness, d) predicted A horizon thickness. Negative values are the result of a spline interpolation between or beyond data points.

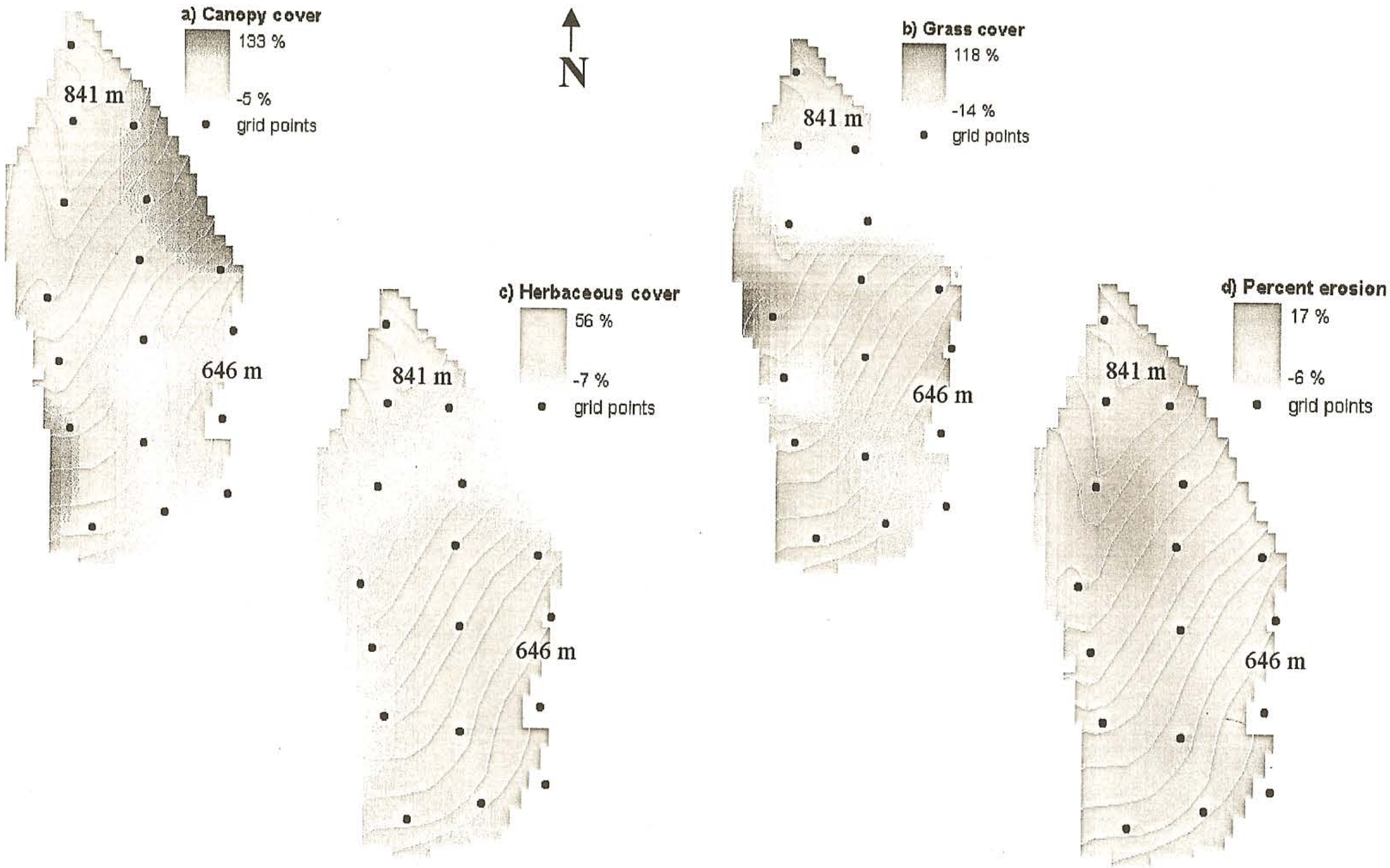


Figure 5.20. Interpolated surfaces of Plot Slawson with, a) Canopy cover, b) Grass cover, c) Herbaceous cover, and d) Erosion. Negative and extreme positive values are the result of a spline interpolation between or beyond data points.

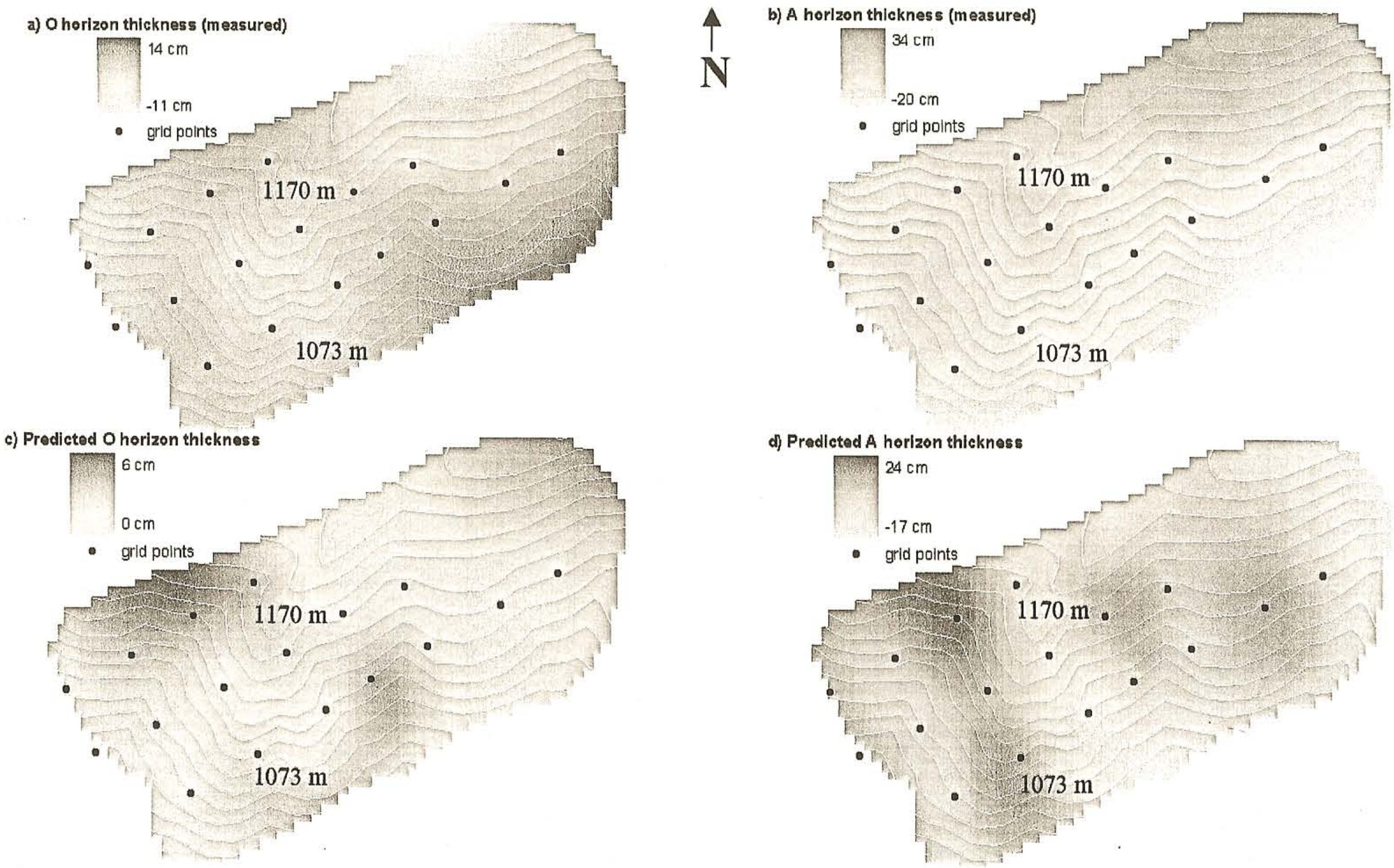


Figure 5.21. Interpolated surfaces of Plot Spromberg with, a) O horizon thickness (measured), b) A horizon thickness (measured), c) predicted O horizon thickness, d) predicted A horizon thickness. Negative values are the result of a spline interpolation between or beyond data points.

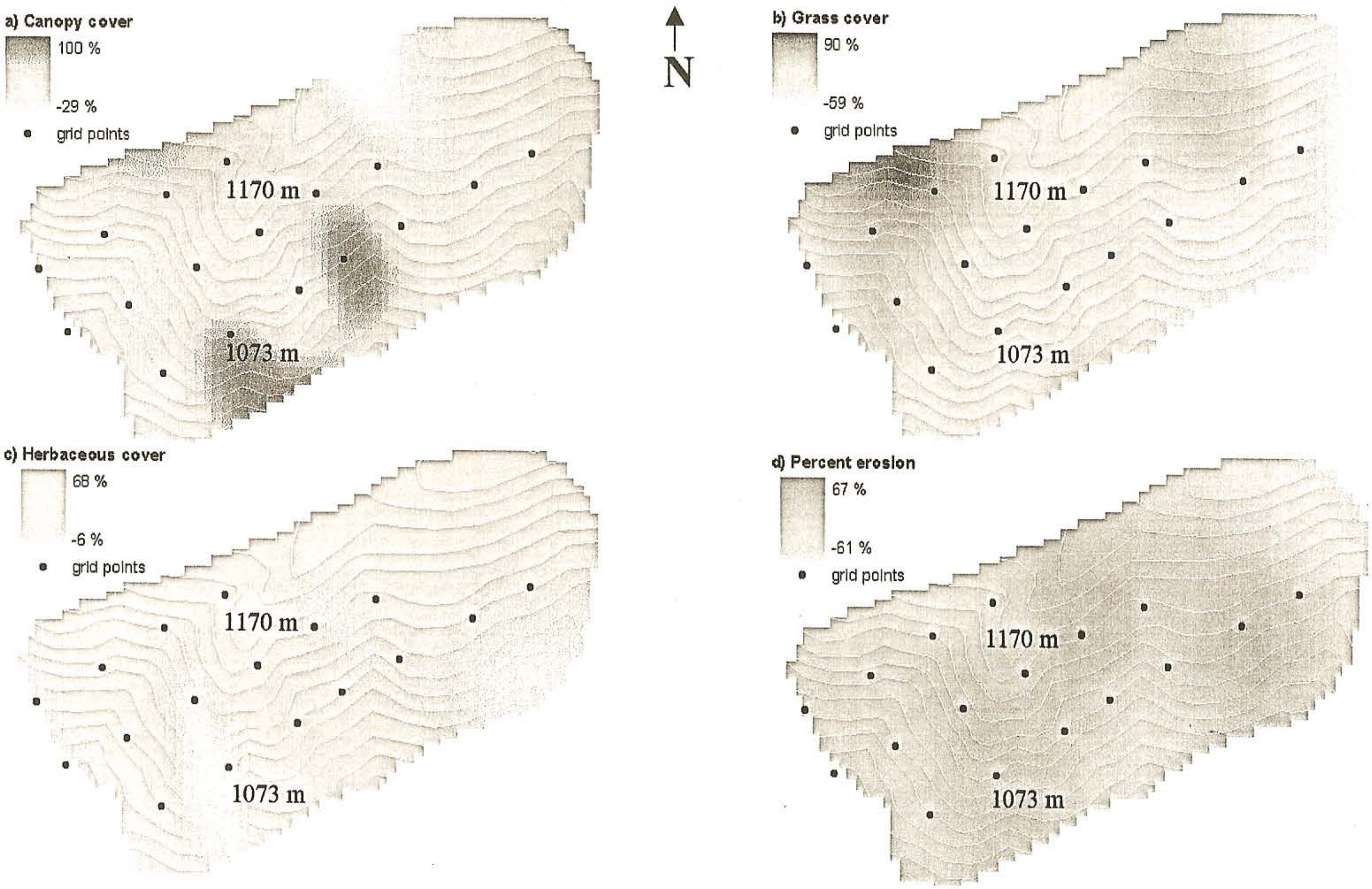


Figure 5.22. Interpolated surfaces for Plot Spromberg with, a) Canopy cover, b) Grass cover, c) Herbaceous cover, and d) Erosion. Negative values are the result of a spline interpolation between or beyond data points.

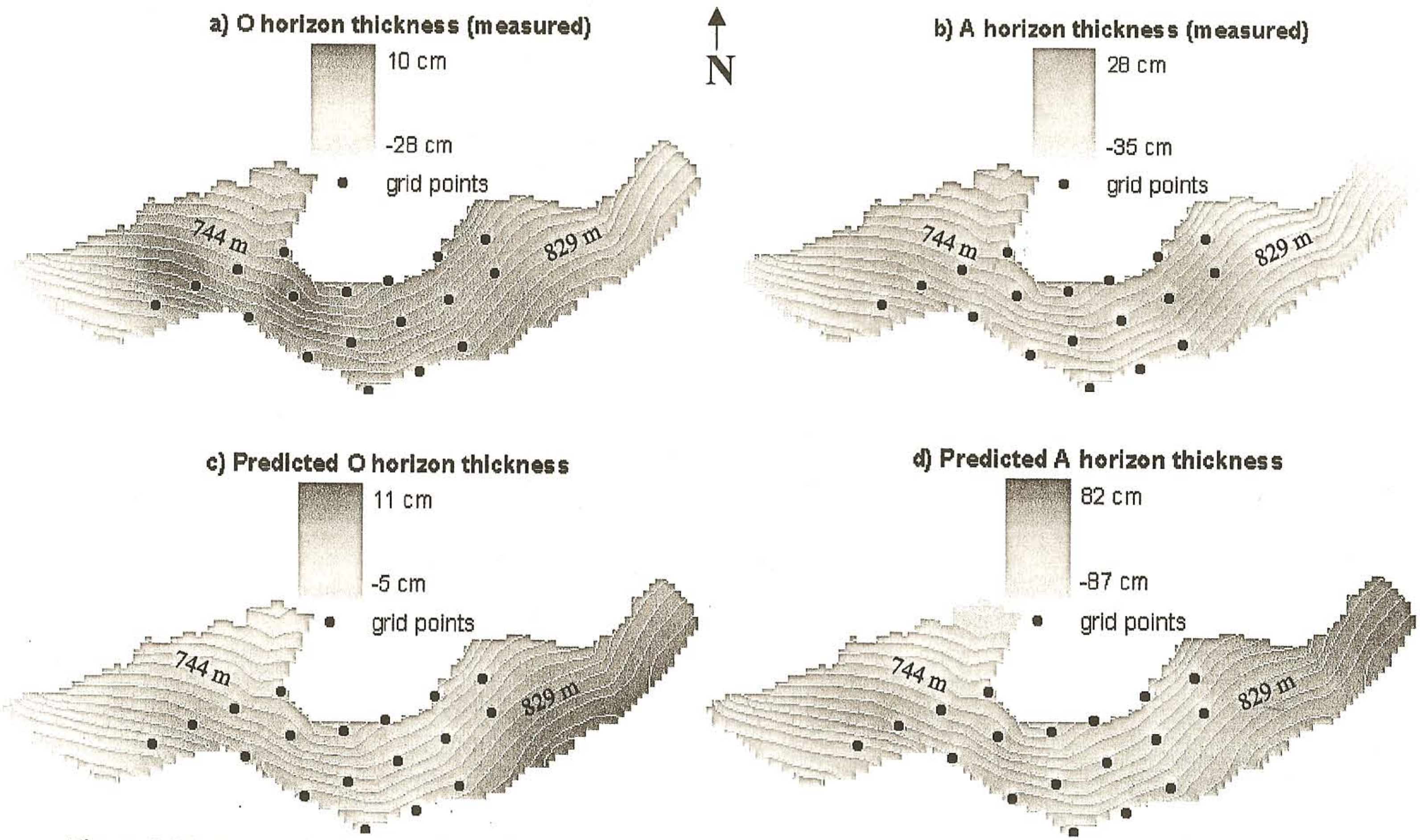


Figure 5.23. Interpolated surfaces of Plot Tripp with, a) O horizon thickness (measured), b) A horizon thickness (measured), c) predicted O horizon thickness, d) predicted A horizon thickness. Negative values are the result of a spline interpolation between or beyond data points.

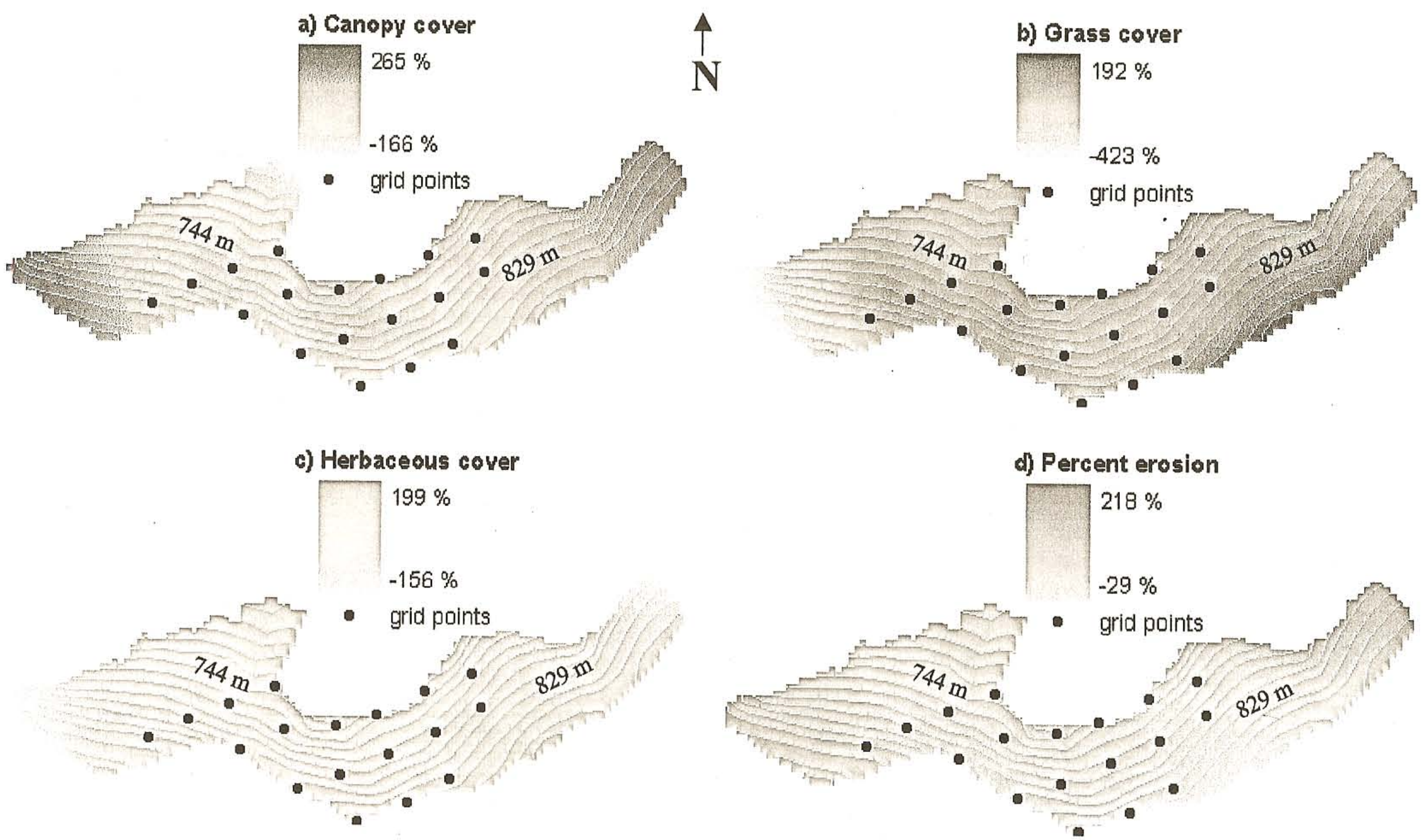


Figure 5.24. Interpolated surfaces of Plot Tripp with, a) Canopy cover, b) Grass cover, c) Herbaceous cover, and d) Erosion. Negative and extreme positive values are the result of a spline interpolation between or beyond data points.

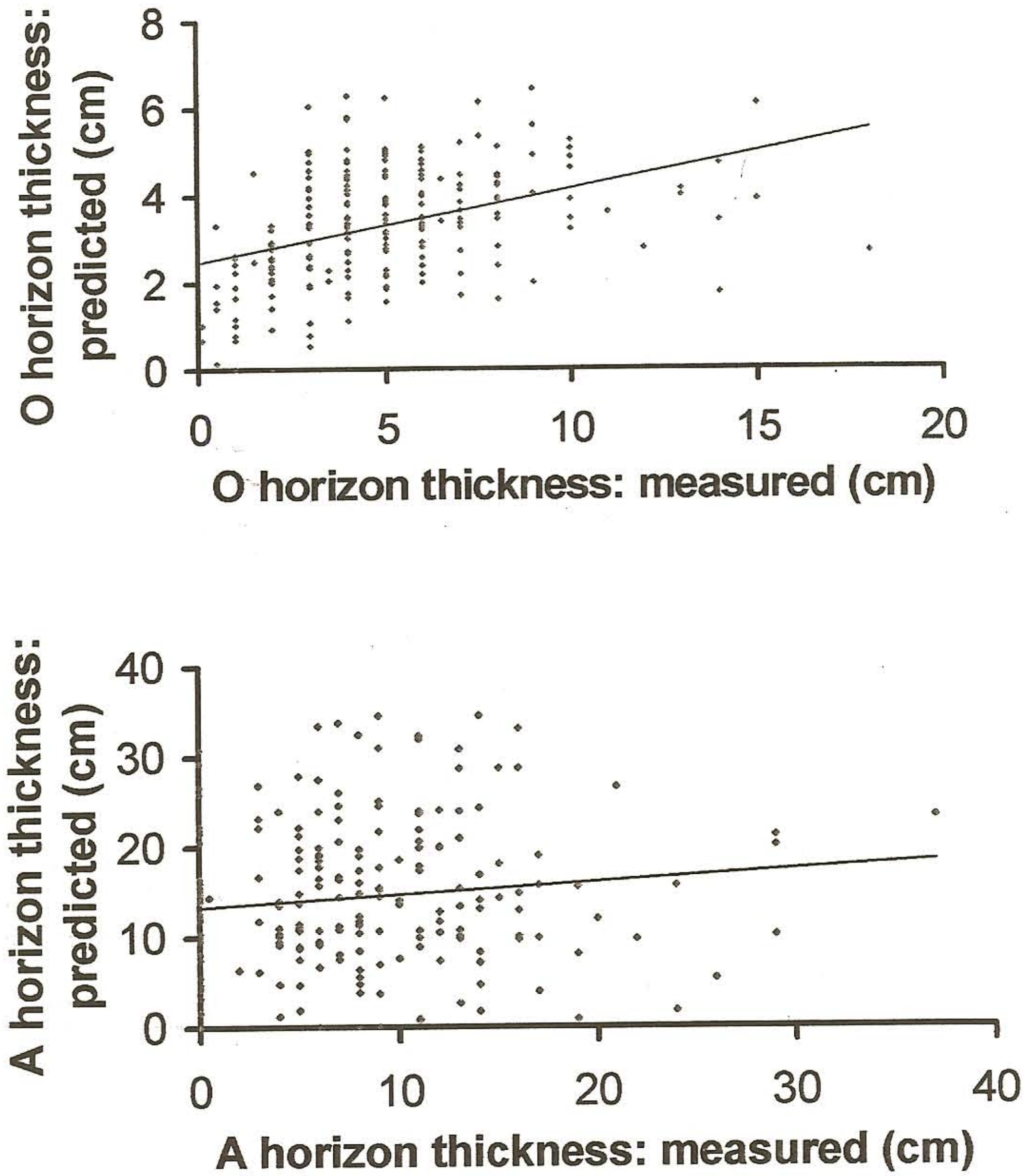


Figure 5.25. Predicted soil horizon thickness over the measured horizon thickness. The line represents the trend of the data. Perfectly predicted horizons would show a 1:1 trend line.

Table 5.1. Plot variability of Camas, Crow 1 and Crow3. Vegetative and erosion variables were collected on a categorical scale; therefore the means displayed for these variables are the ranges in the average category. Standard deviations could not be calculated due to the categorical data.

Plot Camas	Range	Mean	Standard Deviation
Slope (%)	10-67	39	17
Canopy Cover (%)	1-100	36-60	
Grass Cover (%)	0-60	16-35	
Shrub Cover (%)	0-85	36-60	
Herbaceous Cover (%)	0-35	1-15	
Sheet Erosion (% area)	0-60	1-15	
O Horizon thickness (cm)	0.5-8	4	2.5
A Horizon thickness (cm)	0-17	5	5
A Horizon Bulk Density (g/cm^3)	0.7-1.6	1.2	0.23
B Horizon Bulk Density (g/cm^3)	1.0-1.6	1.3	0.18

Plot Crow 1	Range	Mean	Standard Deviation
Slope (%)	10-40	24	9
Canopy Cover (%)	1-100	16-35	
Grass Cover (%)	1-85	36-60	
Shrub Cover (%)	0-85	16-35	
Herbaceous Cover (%)	0-35	1-15	
Sheet Erosion (% area)	0-15	0-1	
O Horizon thickness (cm)	2-10	6	2
A Horizon thickness (cm)	0-15	8	4
A Horizon Bulk Density (g/cm^3)	1.0-1.5	1.2	0.13
B Horizon Bulk Density (g/cm^3)	1.1-1.6	1.3	0.14

Plot Crow 3	Range	Mean	Standard Deviation
Slope (%)	20-70	44	17
Canopy Cover (%)	0-100	16-35	
Grass Cover (%)	0-85	36-60	
Shrub Cover (%)	0-100	16-35	
Herbaceous Cover (%)	1-35	1-15	
Sheet Erosion (% area)	0-35	1-15	
O Horizon thickness (cm)	0.5-15	5.5	3
A Horizon thickness (cm)	0-24	9	6
A Horizon Bulk Density (g/cm^3)	0.8-1.2	1.0	0.11
B Horizon Bulk Density (g/cm^3)	1.1-1.4	1.3	0.10

Table 5.3. Plot variability of Ruby, Sand 2, and Sand 19. Vegetative and erosion variables were collected on a categorical scale; therefore the means displayed for these variables are the ranges in the average category. Standard deviations could not be calculated due to the categorical data.

Plot Ruby	Range	Mean	Standard Deviation
Slope (%)	20-80	54	16
Canopy Cover (%)	1-100	36-60	
Grass Cover (%)	1-85	16-35	
Shrub Cover (%)	0-60	16-35	
Herbaceous Cover (%)	1-60	16-35	
Sheet Erosion (% area)	0-60	1-15	
O Horizon thickness (cm)	0.5-18	6	4
A Horizon thickness (cm)	0-17	7	6
A Horizon Bulk Density (g/cm^3)	1.1-1.5	1.3	0.11
B Horizon Bulk Density (g/cm^3)	1.1-1.5	1.4	0.11

Plot Sand 2	Range	Mean	Standard Deviation
Slope (%)	20-90	58	20
Canopy Cover (%)	16-100	61-85	
Grass Cover (%)	0-100	16-35	
Shrub Cover (%)	0-60	16-35	
Herbaceous Cover (%)	0-15	1-15	
Sheet Erosion (% area)	0-85	16-35	
O Horizon thickness (cm)	3-15	6	3.5
A Horizon thickness (cm)	0-29	8	7
A Horizon Bulk Density (g/cm^3)	0.7-1.2	1.0	0.16
B Horizon Bulk Density (g/cm^3)	1.0-1.4	1.2	0.09

Plot Sand 19	Range	Mean	Standard Deviation
Slope (%)	35-70	61	10
Canopy Cover (%)	0-100	36-60	
Grass Cover (%)	0-100	36-60	
Shrub Cover (%)	0-35	1-15	
Herbaceous Cover (%)	0-60	16-35	
Sheet Erosion (% area)	0-60	16-35	
O Horizon thickness (cm)	1-14	5	3
A Horizon thickness (cm)	0-9	3.5	3
A Horizon Bulk Density (g/cm^3)	0.9-1.3	1.1	0.18
B Horizon Bulk Density (g/cm^3)	1.0-1.4	1.2	0.14

Table 5.4. Plot variability of Slawson, Spromberg, and Tripp. Vegetative and erosion variables were collected on a categorical scale; therefore the means displayed for these variables are the ranges in the average category. Standard deviations could not be calculated due to the categorical data.

Plot Slawson	Range	Mean	Standard Deviation
Slope (%)	5-60	43	13
Canopy Cover (%)	0-100	36-60	
Grass Cover (%)	1-100	36-60	
Shrub Cover (%)	0-85	16-35	
Herbaceous Cover (%)	0-60	1-15	
Sheet Erosion (% area)	0-15	1-15	
O Horizon thickness (cm)	0.5-6	4	1.9
A Horizon thickness (cm)	7-17	11	3
A Horizon Bulk Density (g/cm^3)	0.9-1.2	1.1	0.09
B Horizon Bulk Density (g/cm^3)	1.0-1.4	1.2	0.09

Plot Spromberg	Range	Mean	Standard Deviation
Slope (%)	20-75	63	13
Canopy Cover (%)	1-100	16-35	
Grass Cover (%)	0-85	16-35	
Shrub Cover (%)	1-60	16-35	
Herbaceous Cover (%)	0-60	16-35	
Sheet Erosion (% area)	0-85	16-35	
O Horizon thickness (cm)	0.1-7	4	2
A Horizon thickness (cm)	0-14	3	5
A Horizon Bulk Density (g/cm^3)	0.8-1.3	1.0	0.19
B Horizon Bulk Density (g/cm^3)	0.7-1.5	1.2	0.19

Plot Tripp	Range	Mean	Standard Deviation
Slope (%)	15-85	64	20
Canopy Cover (%)	1-100	36-60	
Grass Cover (%)	1-85	36-60	
Shrub Cover (%)	0-100	16-35	
Herbaceous Cover (%)	0-85	16-35	
Sheet Erosion (% area)	0-60	1-15	
O Horizon thickness (cm)	1-9	4	2
A Horizon thickness (cm)	0-26	12	8
A Horizon Bulk Density (g/cm^3)	0.8-1.2	1.1	0.09
B Horizon Bulk Density (g/cm^3)	1.0-1.4	1.2	0.11

Table 5.5. The area soil and site characteristics of all study plots combined shows upland properties of the Northeast Wenatchee Mountain area. The values used to determine ranges, means and standard deviations for the study area are the mean values from the individual plots. Vegetative and erosion variables were collected on a categorical scale; therefore the means displayed for these variables are the ranges in the average category. Standard deviations could not be calculated due to the categorical data.

All Plots	Range	Mean	Standard Deviation
Slope (%)	24-64	46	14
Canopy Cover (%)	16-85	36-60	
Grass Cover (%)	16-60	36-60	
Shrub Cover (%)	1-60	16-35	
Herbaceous Cover (%)	1-35	1-15	
Sheet Erosion (% area)	1-35	1-15	
O Horizon thickness (cm)	4-6	5	1
A Horizon thickness (cm)	3-12	8	3
A Horizon Bulk Density (g/cm^3)	1.0-1.3	1.1	0.1
B Horizon Bulk Density (g/cm^3)	1.2-1.4	1.3	0.1

CHAPTER 6: CONCLUSIONS

The Fire and Fire Surrogate site, located on the east slopes of the Washington Cascades, exhibits high topographic variability, with some very steep slopes. Vegetation type patches were also observed; this is where one vegetation type, such as grass, comprises a large proportion of the total vegetation in a patch. The study area is large, encompassing approximately 25 square km. However, the climate, parent material, age and vegetation species are relatively constant over the entire study area.

Considering the amount of topographic variation present on the site, only eight substantially different soil types were found. Forty-four of forty-eight soils were described using only five soil types. However, the stages of development among these five soil types vary widely from young, thin soils lacking an A horizon to mature, deep soils with multiple Bt horizons.

Significant linear regression models were generated, using data blocked by topographic position from soil profiles. Percent tree and grass cover, aspect, and percent erosion explained 41 % of the variation in the O horizon thickness model. Percent herbaceous and grass cover contributed to the A horizon thickness model, explaining 31 % of the variability. Erosion was significant in determining the Bw horizon explaining 39 % of the variability. Erosion, and percent grass cover contributed in explaining 41 % of variation in the depth to the C horizon. Due to the variability and long terms effects of topography on the landscape, topography was expected be the most important factor affecting soil horizon depth. However, vegetation was most consistently important in the regression models, and of the topographic variables, only aspect, not slope percent or topographic position affect horizon depth.

O and A horizon thickness models were applied to the small-scale data collected from the grid points to determine the accuracy of the predicted values. GIS maps and scatter plots show the predicted values for O horizon thickness being more accurate than the predicted thickness for A horizon. This is not surprising given the longer time required to form an A horizon compared to an O horizon. The environmental factors and processes that contribute to the O horizon formation, such as litterfall, decomposition, and erosion, operate on shorter time scales and are more evident than the long-term processes, such as lessivage, that result in mineral soil development.

One objective of this study was to determine if predictable soil patterns or models could be derived. GIS application of the regression equations to the grid points showed some, but not perfect fit to the measured data. Thirty to forty percent of the soil variation is explained with the models, which primarily use vegetation as predictor variables. Other environmental factors may need to be considered to improve soil predictions. For example, the disturbance history of the study area is extensive and not well recorded for both recent and distant past events. The effects disturbance has had on the landscape may be a significant contributing factor to the current soil conditions. Other factors that could improve soil horizon predictions are better mapping of volcanic ash and fire history.

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APPENDIX A: SOIL DESCRIPTIONS

NOTE: Parent material of the following soils may include, in addition to the specified bedrock, various amounts of ash deposits, from volcanic eruptions or past fires, colluvium, from erosion and deposition on site, and/or loess deposits. All colors and consistencies are for moist soils. Plasticity is for wet soils.

Soil 1 (5 soils)

Found on backslopes and ridges with little vegetation. Slopes range from 35-85% with north, northwest, south, west or southwest aspects. Elevation ranges from 700-940m. Vegetation is made up of 20-50% mixed Ponderosa pine/Douglas-fir canopy, 10-40% Bitter brush (*Purshia tridentata*), >5-55% pinegrass (*Calamagrostis rubescens*) and a mix of shrub and forb species. Parent material consists of sandstone from the Chumstick formation. Sheet erosion ranges from 0-60% of the area. Evidence of past fire may be present.

Typical profile

O horizon: discontinuous – 8 cm thick.

Bw horizon (may not be present, found in 3 of 5 soils): 0 – 40 cm thick; 2.5 Y 3/2 to 10 YR 4/3; sandy loam or loamy sand; weak, fine to medium, granular or moderate, medium, angular blocky structure; very friable consistence; non-plastic; many or common fine roots, common to few medium roots, possibly few coarse roots.

C, Cr, or BC horizon: 9 – 11 cm thick; 2.5 Y 4/3 to 10 YR 5/6; sand, sandy loam or weathered sandstone; massive weathered sandstone to strong, coarse, angular blocky, or weak, fine, granular structure; very friable or loose consistence; non-plastic; fine roots range from few to many, few medium and coarse roots possible.

R horizon or colluvium: 11 – 51 from surface with a massive structure.

Soil 2 (2 soils)

Found on a ridge and area bare of vegetation. Slopes range from 25-45% with south or southwest aspects. Elevation ranges from 1120-1146m. Vegetation is made up of 40-60% mixed Ponderosa pine/Douglas-fir overstory and a variety of species of shrubs, forbs, and grasses in the understory, no one species composing more than more than 10% cover. Parent material is sandstone, shale and conglomerate from the Swauk formation. Minor erosion is exhibited through breaking and sliding of the O horizon.

Typical profile

O horizon: discontinuous to 2 cm thick.

A horizon: 8 – 11 cm thick; 10 YR 3/2 to 10 YR 3/3; sandy loam or loam; weak, medium, sub-angular blocky parting to weak, fine, granular structure; friable or very friable consistence; non-plastic; common very fine roots, many fine roots, and few medium roots possible.

Cr horizon: 8 – 11 cm from the mineral soil surface; 10 YR 3/3 to 10 YR 3/4, organic stains on weathered sandstone 10 YR 2/1 to 10 YR 4/3; sand texture; weak, medium, granular and broken sandstone structure; non-plastic; very fine and fine roots possible.

Soil 3 (9 soils)

Found mostly on slopes and ridges and a few valleys. Slopes range from flat ridge tops (0%) to 65% with south, southwest, southeast and west aspects. Elevation ranges from 695-1146m. Vegetation is made up of >15-80% mixed Ponderosa pine/Douglas-fir overstory and a variety of shrubs, forbs and grasses in the understory, with every site containing some percent pinegrass (*Calamagrostis rubescens*) (<5-90%). Abies grandis may be present (5%) in the canopy. The parent material is sandstone, shale and conglomerate from the Chumstick and Swauk formations. Colluvium may also make up the parent material, especially in deeper horizons. Sheet erosion can be present, however it is usually <15% of the area.

O horizon: discontinuous to 8.5 cm thick.

A horizon: 3 – 38 cm thick; 10 YR 3/1 to 10 YR 4/4; gravelly loam, sandy loam, loam, or sandy clay loam; weak, fine, granular to moderate, medium, sub-angular blocky structure; very friable, friable, or firm consistence; non-plastic to very plastic; very few to many, very fine, fine, medium and coarse roots possible.

Bt(1) horizon (more than one Bt horizon may or may not be present): 6 – 46 cm thick; 10 YR 4/3 to 5 YR 4/4; sandy clay loam, clay loam, or loam; weak, fine, granular to moderate to strong, medium to coarse, sub-angular or angular blocky structure; very friable to very firm consistence; non-plastic to very plastic; few very fine, few to many, fine and medium, and very few to few, coarse roots possible; very few to many, thin to moderately thick cutans possible on ped faces, pores or as bridges.

Bt2 horizon (may not be present, found in 7 of the 9 soils): 0 – 45 cm thick; 7.5 YR 3/3 to 10 YR 5/6; sandy clay loam or clay loam; weak or moderate, medium angular blocky, moderate, coarse or strong, medium sub-angular blocky, or strong, coarse, angular blocky structure; firm to extra firm consistence; slightly plastic to very plastic; very few to few, very fine and coarse roots, few to many, fine and medium roots; few to common thin cutans in pores and on ped faces, common to very many moderately thick cutans present on ped faces, pores and as bridges.

Bt3 horizon (may not be present, found in 3 of the 9 soils): 0 – 20 cm thick; 7.5 YR 4/4 to 10 YR 5/4; clay loam or gravelly clay loam; moderate to strong, medium to coarse, sub-angular blocky structure; friable to very firm consistence; very few to common, medium and coarse roots; common to very common, thin to thick cutans present on ped faces and in pores.

BC, BCt, C, Crt, or R horizon: 30 – 91 cm from the mineral soil surface; 10 YR 4/6 to 10 YR 5/8; sandy clay, sandy clay loam, sand or weathered sandstone; weak, fine, granular, moderate to strong, medium, angular or sub-angular blocky, or strong, medium, platy (from flaking weathered sandstone) structure; friable to very firm consistence; non-plastic to slightly plastic; very few to few, fine, medium and coarse roots possible; common, moderately thick cutans possible in pores, on ped faces and as bridges.

Soil 4 (13 soils)

Found mostly on slopes and ridges and a few valleys. Slopes range from flat ridge tops (0%) to 70% with almost any aspect (north, northeast, northwest, west, southwest, south, and southeast). Elevation ranges from 680-1170m. Vegetation is made up of 5-90% mixed Ponderosa pine/Douglas-fir canopy, 0-90% pinegrass (*Calamagrostis rubescens*), present on almost all sites, and a variety of shrubs, forbs, and other grasses. The parent material is sandstone, shale and conglomerate from the Chumstick and Swauk formations. Sheet erosion can occur, however it is not prominent on most sites ranging from 0-35%. Evidence of past fire and logging may be present.

O horizon: discontinuous– 9 cm thick.

A(1) (an A horizon is not found at one site, the first horizon is an AB): 0 – 24 cm thick; 5 Y 2.5/1 to 10 YR 5/3; loam, sandy clay loam, or sandy loam; weak to moderate, very fine to medium, granular or fine to moderate, medium to coarse, sub-angular blocky structure; friable, loose or firm consistence; non-plastic to plastic; very few to many, very fine and fine roots, few to common, medium roots, and few coarse roots possible.

A(2) (may not be present, found in 3 of 13 soils): 0 - 19 cm thick; 10 YR 3/2; sandy clay loam or loam; moderate to strong, medium to coarse, sub-angular structure; firm to extra firm consistence; non-plastic to plastic; many, very fine roots, few to common fine roots, and few medium roots possible.

AB or BA horizon: 5 – 47 cm thick; 2.5 Y 3/2 to 10 YR 5/4; sandy clay loam sandy loam, clay loam, or loam; weak to strong, fine to coarse, sub-angular blocky to angular blocky or strong, fine, prismatic structure; friable to extra firm; non-plastic to very plastic; few to many, very fine and fine roots, few to common, medium and coarse roots; very few to common, thin cutans possible in pores and on ped faces.

Bt(1) (may not be present, found in 12 of 13 soils, more than one Bt horizon may or may not be present): 0 - 59 cm thick; 2.5 Y or 10 YR 4/3 or 7.5 YR 4/4 to 2.5 Y or 10 YR 5/4 or 7.5 YR 4.6; sandy clay loam, clay loam, or silty clay; moderate to strong, medium to very coarse, sub-angular structure; friable to extra firm consistence; slightly plastic to very plastic; very few to common, fine, medium and coarse roots; few to many, thin to moderately thick cutans possible on ped faces, in pores and as bridges.

Bt2 horizon (may not be present, found in 3 of 13 soils): 0 – 31 cm thick; 7.5 YR 4/6 to 10 YR 6/4 to 2.5 Y 5/6; silty clay or sandy clay loam; weak to moderate, medium sub-angular blocky structure; friable to firm consistence; plastic; few to common, fine and medium roots, few coarse roots; many to common, thin to moderately thick cutans on ped faces and pores.

BC, BCr, or BCt horizon (may not be present, found in 6 of 13 soils): 13 - >59 cm thick; 10 YR 3/3 to 10 YR 5/6 or 2.5 Y 4/4; clay loam or sandy clay loam; moderate to strong, medium to coarse, sub-angular blocky to angular blocky structure; firm to extra firm consistence; slightly plastic to very plastic; very few to common, very fine, fine, medium and coarse roots; very few to very many, thin to moderately thick cutans possible on ped faces, pores and as bridges.

C, Cr, or R horizon: 34 - 99 cm from surface of mineral horizon; 2.5 Y 4/4; to 10 YR 5/6 to 10 YR 7/4; sandy clay loam to weathered sandstone; weak, fine granular, to strong, medium to very coarse, sub-angular to angular blocky to massive (80% is massive weathered sandstone in one soil) structure; friable to extra firm consistence; very few to common, fine, medium and coarse roots.

Soil 5 (5 soils)

Found on valleys, slopes, and a ridge. Slopes range from 20-70% with south, southwest, west, and north aspects. Elevation ranges from 730-835m. The vegetation is made up of >15-80% mixed Ponderosa pine/Douglas-fir canopy, 20-90% pinegrass (*Calamagrostis rubescens*), and a variety of shrub, forb, and other grass species. A small percent of the canopy may be Douglas maple (10% on one site). Parent material is sandstone from the Chumstick formation. Erosion impacts were little (<15%) to none, however presence of transition horizons and field notes suggest the occurrence of profile disturbance as well as fire.

O horizon: 1.5 – 8 cm thick.

A(1) horizon (more than one A horizon may or may not be present): 4 – 11 cm thick; 10 YR 3/1 to 10 YR 4/3; loam, silty clay loam, sandy loam, or sand; weak to moderate, fine to medium, granular or weak to moderate, medium, sub-angular structure; loose to friable consistence; non-plastic; few to many, very fine, fine, medium, and coarse roots.

AB or A2 horizon: 22 –33 cm thick; 10 YR 2/1 to 10 YR 4/3; loamy sand, sandy loam, loam, or silty clay loam; weak to moderate, medium to coarse, sub-angular blocky structure; very friable to firm consistence; non-plastic; few to many, fine and medium roots, few coarse roots.

Bw(1) horizon (may not be present, found in 4 of 5 soils, more than one Bw horizon may or may not be present): 0 – 49 cm thick; 10 YR 3/4 to 10 YR 4/3 or 2.5 Y 4/3; loamy sand, silty clay loam, or silt loam; weak to moderate, medium to coarse, sub-angular blocky structure; very friable to firm consistence; non-plastic to slightly plastic; few to many very fine, fine, and medium roots, few coarse roots.

Bw2 horizon (may not be present, found in 2 of 5 soils): 0 – more than 35 cm thick; 10 YR 3/3 to 2.5 Y 5/4; loamy sand; weak to moderate, medium to very coarse, angular blocky to prismatic structure; very friable to friable consistence; non-plastic; very few to common, fine and medium roots, very few to few coarse roots.

BC horizon (may not be present, found in 3 of 5 soils): 0 – more than 73 cm thick; 10 YR 4/3 to 10 YR 5/4 to 10 YR 4/6; loamy sand or sandy clay loam; fine, granular to moderate, very coarse, angular blocky to moderate, medium prismatic structure; very friable to firm consistence; non-plastic; very few to common, fine roots, very few to few medium roots, few coarse roots; few thin cutans present as films on grains.

CB or R horizon: 81 – 132 cm from mineral soil surface; 2.5 Y 3/3 (CB horizon), no R horizon color known; loamy sand (CB horizon), weathered sandstone (R horizon texture); moderate, medium sub-angular blocky (CB horizon), massive (R horizon); firm (CB horizon consistence); non-plastic; very few fine and medium roots (CB horizon).

Soil 6 (12 soils)

Found on ridges, slopes and valleys. Slope ranges from 5-65% with a variety of aspects (southwest, south, northeast, or west). Elevation ranges from 730-1160m. Vegetation is composed of 2-90% mixed Ponderosa pine/Douglas-fir canopy and a wide variety of shrubs, some forbs, and mix of grasses, which usually includes pinegrass (*Calamagrostis rubescens*), in the understory. Abies grandis may be present in the canopy (up to 50%). Ponderosa pine or Douglas-fir may occur without the other tree species in some areas. Grand fir (Abies grandis) presence is possible, although rare (found at one of twelve sites). Parent material is sandstone, shale and conglomerate from the Chumstick and Swauk formations. Ash, colluvium, and/or eolian deposits may also be considered a parent material in some profiles. Charcoal or presence of past fires may be apparent. Erosion is noted at seven of twelve profiles ranging from <15 - almost 100% of the area. Evidence of past fire may be present.

O horizon: discontinuous – 6 cm thick.

A horizon: 2 – 20 cm thick; 10 YR 2/2 to 10 YR 4/3 or 2.5 Y 4/2; loam, sandy clay loam, sandy loam, loamy sandy, or silt; weak to moderate, fine to coarse, granular to weak to moderate, fine to medium, sub-angular blocky to blocky structure; very friable or friable consistence; non-plastic to plastic; few to many, very fine roots, common to many, fine roots, few to common, medium roots, few to common, coarse roots.

Bw(1) horizon (more than one Bw horizon may or may not be present): 8 – 83 cm thick; 10 YR 3/2 to 10 YR 4/4 or 2.5 Y 4/3 to 2.5 Y 4/4; loam, sandy loam, loamy sand, or sandy clay loam; weak, fine to coarse, granular to weak to strong, medium to coarse, sub-angular blocky structure; very friable to firm consistence; non-plastic to slightly plastic; few to many, very fine, fine and medium roots, few to common coarse roots.

Bw2 horizon (may not be present, found in 2 of 12 soils): 0 – 34 cm thick; 10 YR 4/2; sandy loam or sandy clay loam; moderate, medium sub-angular blocky structure; very friable consistence; slightly plastic; few to common, fine, medium and coarse roots; few thin cutans possible.

BC or C horizon (may not be present, BC horizons found in 5 soils and C horizons in 2 of 12 soils): 0 – 59 cm thick; 10 YR 3/1 to 10 YR 5/6; sandy clay loam, sandy loam, loamy sand, or sand; weak, fine, granular or weak to moderate, medium to coarse, sub-angular blocky structure; loose to friable consistence; non-plastic to slightly plastic; few to many, medium roots, few to common, fine roots, few coarse roots; few to common thin cutans possible.

R horizon: 19 – 103 cm from the mineral soil surface; 10 YR 5/4, 2.5 Y 5/3, or 2.5 Y 5/4; sand or weathered sandstone; moderate, medium, sub-angular blocky or massive structure; unknown consistence; common, fine roots and few medium roots possible; common, thin cutans possible.

Soil 7 (1 soil)

Found in a valley. Slope is 20% with a south-southwest aspect and elevation is ~ 750m. Vegetation is composed of mixed Ponderosa pine/Douglas-fir canopy, 30-95% pinegrass (*Calamagrostis rubescens*), and a variety of other shrubs, forbs and grasses in the understory. Parent material is ash, which is found from the A1 to the top of the 2BCb, and sandstone from the Chumstick formation. No erosion is present. Many dead trees are in the area, probably from pine beetle kills. No charcoal is evident in the profile.

O horizon: 4 cm thick.

A1 horizon: 29 - 31 cm thick; 10 YR 3/3; loam; weak, fine, sub-angular blocky structure; friable consistence; slightly plastic; many fine roots, few medium rootst.

A2 horizon: 47 - 60 cm thick; 10 YR 3/4; sandy loam; moderate, medium sub-angular blocky structure; friable consistence; slightly plastic; common, fine roots, few, coarse roots.

C horizon: 27 – 35 cm thick; 10 YR 6/4; sandy loam; weak, fine, prismatic structure; firm consistence; slightly plastic; few medium and coarse roots.

2BCb horizon: 122 cm from mineral soil surface, >33 cm thick; 2.5 Y 5/6; sandy clay loam; moderate, coarse, sub-angular blocky structure; friable consistence; slightly plastic; very few, fine, medium and coarse roots.

Soil 8 (1 soil)

Found in a valley. Slope is 15% with a south aspect and elevation is ~ 730m. Vegetation is made up of 80% evenly mixed Ponderosa pine/Douglas-fir overstory and 80% pinegrass (*Calamagrostis rubescens*) with a variety of shrub and forb species in the understory. Parent material is sandstone from the Chumstick formation and colluvium from erosion upslope. Sheet erosion is evident and gully erosion is present in the area. Evidence of fire is also present with charcoal in the buried horizon and burned roots in the C horizon.

O horizon: 4 cm thick.

A horizon: 23 cm thick; 10 YR 2/1; loamy sandy; weak, fine, granular structure; very friable consistence; many very fine roots, common, fine roots, few coarse roots.

Bw horizon: 11 cm thick; 10 YR 3/2; sandy loam; weak, fine, granular structure; friable consistence; common, very fine, medium and coarse roots.

C horizon: 44 cm thick; 2.5 Y 4/3; sand; fine, granular to single grain structure; loose consistence; few fine and coarse roots.

CB horizon: 23 cm thick; 10 YR 3/3; loamy sand; fine, granular to single grain structure; very friable consistence; common, fine roots, few, coarse roots.

Bwb horizon: 102 cm from mineral soil surface; 10 YR 3/2; sandy loam; moderate, medium, blocky structure; very friable consistence; few, very fine roots, common, fine roots.